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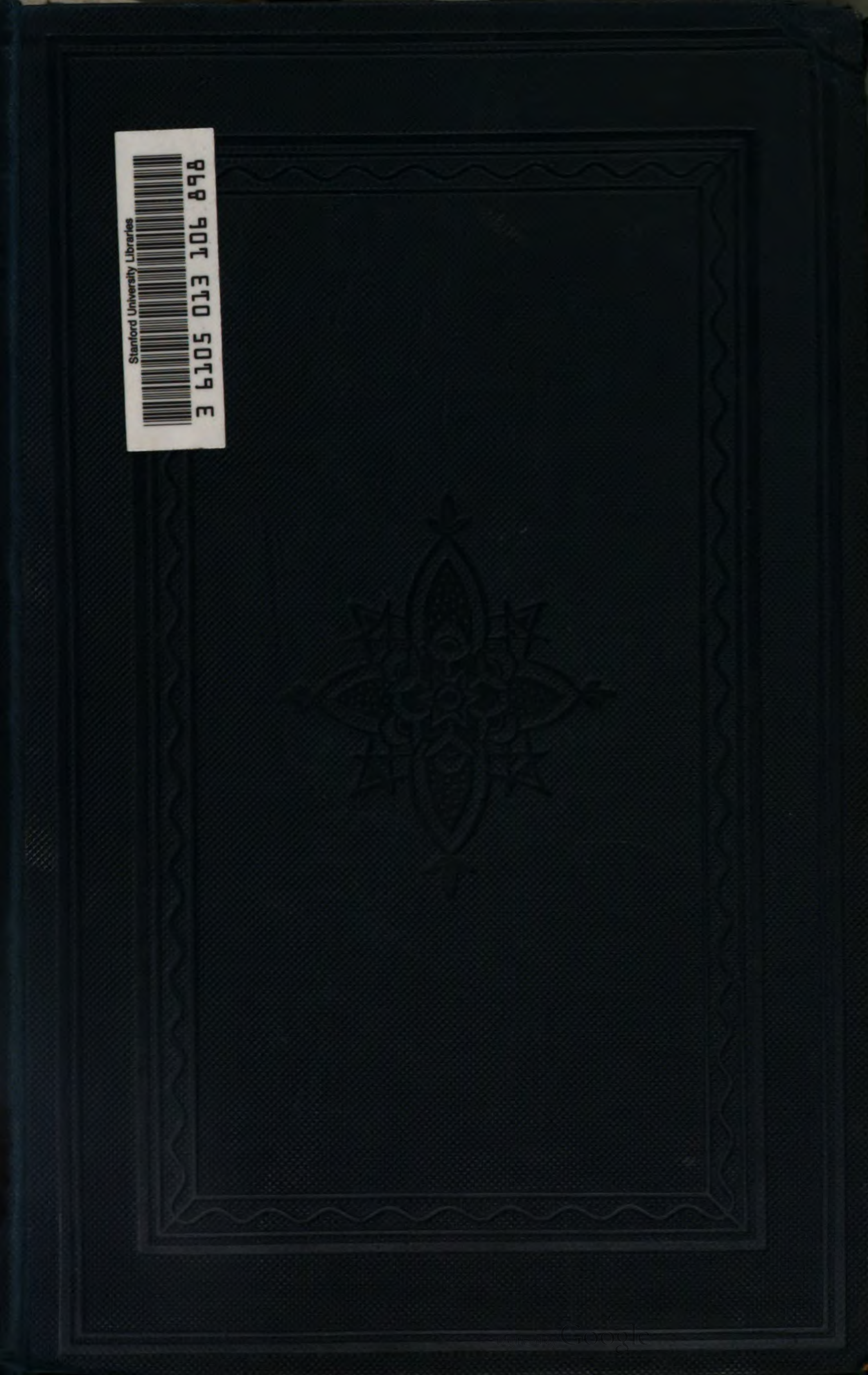

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MINUTES OF PROCEEDINGS

OF THE

INSTITUTION

OF

CIVIL ENGINEERS;

WITH

ABSTRACTS OF THE DISCUSSIONS.

VOL. XXII.

SESSION 1862-63.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

INDEX. PAGE 643.

LONDON:
Published by the Institution,
25, GREAT GEORGE STREET, WESTMINSTER, S.W.
1863.

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THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1862-63.

November 11, 1862.

JOHN ROBINSON M'CLEAN, Vice-President, in the Chair.

At the commencement of the proceedings, Mr. M'Clean, V.P., in the absence of the President, said it was his duty to notice the loss the Institution had sustained by the death, during the recess, of two of its most eminent Members, Mr. John Edward Errington, Vice-President, and Mr. James Walker, Past-President.

For upwards of thirty years, indeed ever since the introduction of the railway system, Mr. Errington occupied a prominent position as an Engineer; and, in conjunction with Mr. Locke, executed some of the principal railway works in Great Britain. He was, like his partner, Mr. Locke, a strong advocate for economy in the first cost of construction. By his death the profession had lost one of its most distinguished members, the Institution one of its warmest supporters, and many, a sincere friend, who was ever ready to afford advice, especially to his numerous pupils and assistants, whose interests it was his constant endeavour to advance. As many of his pupils were actively engaged in the practice of the profession, and had, through his influence, been enabled already to take good positions, Mr. M'Clean expressed the hope, that they would feel it a duty, no less than a pleasure, incumbent upon them, to communicate plans and descriptions of the works of their eminent masters, so as to keep alive the memory of "Locke and Errington" in the Institution of Civil Engineers. Mr. Errington had proved his attachment to the Institution, and his desire to see it prosper, by bequeathing to it the sum of ONE THOUSAND POUNDS, free of legacy duty, without attaching any condition whatever to the gift.

Mr. Walker was one of the oldest Members of the profession, having been in active practice as an Engineer for upwards of sixty years. He was also one of the earliest Members of the Institution, having joined it in the year 1823, and, after the death of Mr. Telford, he became its President. For a period of eleven years, during which he so ably conducted its proceedings in that capacity, he was most devoted to its interests, and to his zeal and energy must be greatly attributed the eminent position it held on his retiring from the Chair in 1845. Mr. Walker's name was associated with many of the greatest hydraulic works in England and Scotland, including lighthouses, harbours, bridges, embankments, and drainage. His opinion was much valued by the Elder Brethren of the Trinity House, by the Lords of the Admiralty, and by the Corporation of the City of London; and it must not be forgotten, especially at the present moment, that twenty years ago he laid down lines for embanking each side of the River Thames, which had never been improved. Having had the privilege of being in Mr. Walker's employment for many years prior to 1844, Mr. M'Clean had had an opportunity of knowing his worth, and while expressing gratitude for many personal acts of kindness, must state that it was Mr. Walker's constant endeavour to promote the interests of those engaged under him. Many members of the profession had also been trained in the same school, including Burges, Bidder, Hawkshaw, Borthwick, and Hartley. During his long and useful career, he had secured the admiration and respect of numerous influential friends, as well as the regard of his professional brethren.

Mr. M'Clean had much gratification in announcing, that Mr. Walker having left at Mr. Burges' disposal the twenty-five remaining copies of Telford's "Life and Works," as well as the copyright and the copper-plates, Mr. Burges had, in the most handsome and liberal manner, presented them to the Institution.

No. 1,071.—"The Railway System of Germany."[1] By ROBERT CRAWFORD, Assoc. Inst. C.E.

THERE are few subjects which afford, at the present day, more varied and interesting questions for consideration than the growth and development of railways. Whether viewed with regard to the general influence which they exert on the commerce of nations, or their beneficial effect in promoting the introduction of improvements in machinery and manufactures, they cannot fail to present abundant matter for examination and reflection. Nor can an outline of their progress within fixed territorial limits be without some value, in furnishing and grouping together the elements of information, which may aid in the formation of correct opinions, as to the advantages and defects of certain systems.

---

[1] The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

It is in this latter respect that Germany has been selected as the field of investigation for this Paper, since, although in the first instance railways were there adopted with reserve and caution, their construction was afterwards prosecuted with considerable steadiness of purpose, and with but slight fluctuations in the regularity of their progress, except such as arose from political questions, or state policy. In Germany, as in England, tramways formed the germ from which subsequent enterprise developed the vast network of railways now extending throughout the length and breadth of the land, facilitating its commerce, and increasing in no small degree its material prosperity and wealth.

The oldest of these undertakings originated in a fifty years' 'privilege' granted by the Austrian Government, upon the 7th September, 1824, for the construction of a line from Budweiss, in Bohemia, to opposite Linz, on the Danube, a distance of upwards of 80 English miles. In the beginning of the year 1825, this concession was transferred to a Joint-stock Company, formed in Vienna, under the title of "The Imperial Royal First Railway Company of Austria." The works were immediately begun, and about 40 miles finished before the close of 1828. The completion of the remaining portion occupied until the 1st August, 1832, the day of the opening of the line throughout its entire length. About this time a new project was set on foot, and a concession granted to an association of business firms in Vienna, for a line from Linz to Gmünden ($42\frac{1}{4}$ miles), which was made over, in 1834, to the Budweiss and Linz Company. The works were begun in the same year, and finished in 1836. This line, although claiming the name of railway, was in reality a tramway, worked by horses. The gauge was 3 feet $7\frac{1}{2}$ inches in the clear. The rails consisted of flat bars of iron, $2\frac{5}{16}$ inches wide by rather more than $\frac{1}{2}$ an inch in thickness, and weighed $14\frac{1}{4}$ lbs. per yard; they were laid on longitudinal timbers, supported and kept in place by cross sleepers, 6 feet 3 inches apart from centre to centre. The maximum gradients were 1 in 20 on the length between Budweiss and Linz, and 1 in 46 between Linz and Gmünden. The junction of the northern and southern sections was effected by means of a short line, on which occur gradients of 1 in 15 and 1 in 28, passing over the Danube on the timber bridge between Linz and the north shore of the river, which answers for the purposes of ordinary traffic as well as for those of the tramway. The cost of the Budweiss, Linz and Gmünden line was about £4,877 per mile. In 1854, small locomotive engines were adopted for the working of a portion of the southern section, and this system was extended in the following year to the entire length between Linz and Gmünden. The gauge remained the same, but the permanent way was altered on the inclines and sharp curves; the original flat bars and longitudinal timbers having been replaced by small solid rails of the contractors, or broad-based pattern, laid on transverse sleepers. Still more recently, the whole of this undertaking has been incorporated with that of the "Empress Elisabeth Western Railway of Austria," from Vienna to Passau and Salzburg; and it is contemplated, eventually, to convert both the branches to Budweiss and Gmünden into ordinary railways, with the regular normal gauge of 4 feet 8½ inches.

Returning from the digression occasioned by tracing down to a recent period the salient points in the history of what was not only the first line in Austria, but in all Germany, the enterprise which next attracts attention is that of a proposal for connecting Prague with Pilsen, by means similar to those already described. The works were begun in 1828, and a portion of the line was opened in 1830. The original project was never completed, and a length of 34½ miles of tramway, the extent to which it was carried into execution, after changing ownership twice, was finally made over to a Colliery Company for local purposes.

These preliminary remarks bring down the subject to the most important and decisive period in its history, occasioned by the proposal to adopt steam as a motive power instead of horse labour; a proposition carried into effect for the first time in Germany in the case of a railway 4 miles in length from Nürnberg to Fürth, which was opened for public traffic on the 7th December, 1835. The works on this line were unimportant, and presented no engineering difficulties whatever, occupying only nine months in their construction. The cost was £4,745 per mile. The rails, which were for a single way, were laid for about three-fourths of the distance on stone blocks, and the remainder on timber sleepers, which were subsequently replaced by stone supports. The maximum gradient was 1 in 250.

Thus Germany, possessing, at the close of the year 1835, upwards of 108 miles of tramways, had up to the same time only 4 miles of railway, properly so called.

The five years following in regular succession from this date served to introduce railways into all parts of the country, and to give them a fair start. It appears that upon the 31st December, 1840, five years after the completion of the first line, there were twelve railways in Germany, either wholly or in part finished, and yielding a total length opened, equivalent to 377 miles. These, arranged according to the priority of opening of any part of them, assume the following order; it being premised, that those lines worked by steam power are alone referred to:—

1st	Railway in Germany was that from	Nürnberg to Fürth, opened			7th Dec. 1835.
2nd,	„	Leipzig to Dresden, a portion of which was opened			24th Apr. 1837.
3rd,	„	Vienna to Oderberg	„	„	23rd Nov. 1837.
4th,	„	Berlin to Potsdam	„	„	22nd Sept. 1838.
5th,	„	Düsseldorf to Elberfeld	„	„	15th Oct. 1838.
6th,	„	Brunswick to Wolfenbüttel	„	„	1st Dec. 1838.
7th,	„	Magdeburg to Leipzig	„	„	29th June 1839.
8th,	„	Cologne to the Belgian frontier		„	2nd Aug. 1839.
9th,	„	Munich to Augsburg	„	„	1st Sept. 1839.
10th,	„	Frankfort-on-Maine to Wiesbaden		„	26th Sept. 1839.
11th,	„	Berlin to Anhalt	„	„	1st Sept. 1840.
12th,	„	Mannheim to Heidelberg	„	„	12th Sept. 1840.

Such was the position of railways at the close of the year 1840, after which they became so numerous and varied that it would be impossible, keeping in view the object of this Paper, to follow them any further in detail. It is sufficient for the present purpose to review in general terms their progress from time to time, from their first adoption down to the present day, as exhibited in the following statement, showing the extent opened at different fixed periods:—

There were	4	miles of Railway	in Germany opened	up to the close of	1835.
„	377	„	„	„	1840.
„	1,817	„	„	„	1845.
„	4,487	„	„	„	1850.
„	5,750	„	„	„	1855.
„	8,512	„	„	„	1860.
„	8,866	„	„	„	1861.

The local distribution of this latter quantity and the cost per mile are as follows:—

In Prussia there were about . .	3,417	miles constructed	at an	£.
average cost per mile of				15,200
In the German provinces of Austria	1,706	„	„	22,700
„ Bavaria	1,172	„	„	13,670
„ Hanover	450	„	„	13,100
„ Saxony	435	„	„	18,350
„ Baden	260	„	„	16,500
„ Würtemburg	260	„	„	14,500
„ the other German States .	1,166	„	„	14,390

Total . . . . 8,866 miles constructed,
at an average cost of about £16,400 per mile.

Nearly one-fourth of the entire length is provided with two lines of rails.

About 38 per cent. of the existing lines are Government property.
„ 10½ „ are the property of Companies, but worked by Government.
„ 51½ „ are the property of, and are worked by private, or Joint Stock Companies.

Many railways which were originally constructed by State means have been sold, or rented to Joint Stock Companies, and the reverse of this has in some instances taken place. Hence it becomes necessary to return to an examination of the manner in which they were at first carried out, in order to estimate the extent to which Government resources participated in these undertakings. In this respect it appears, that

39½ per cent. of the entire length were constructed by the different States.
24¾ „ by Companies under a guarantee of interest, or a Government subvention.
35¾ „ „ at their own cost and risk.

That is to say, Government aid has been granted directly, or indirectly, to nearly two-thirds of the entire system. These 8,866 miles of railway comprise sixty-two different undertakings as at present constituted, under as many separate organisations, and are managed by nineteen Government departments, and forty-three boards of Directors, or some substitute, whose control however is not confined to Germany proper, but extends to adjoining territories, over an aggregate length of 10,830 miles of line.

Not long after the introduction of railways into Germany, it became apparent, that their management would be far from sufficiently perfect to meet the continually increasing requirements of commerce, except some common plan of action could be agreed upon, which would bring all the railways in the country into one large association, for regulating, to a certain extent, their relations with each other, according to general rules, somewhat after the manner of the German political Confederation. For this purpose a conference was held at Cologne, in June, 1847, which resulted in the formation of a society under the title of "The Association of German Railway Directions," which now embraces the whole of the lines already referred to, with very trivial and unimportant exceptions. Each railway subscribes a fixed sum towards the general management fund, together with a variable amount depending upon its length, and is represented at the meetings of the Association and in the debates, in proportion to its importance. Yearly general meetings are held, at a time and place mutually agreed upon, and when considered expedient, special meetings are also called. At all of these, such matters as relate to the interests of the Association are discussed and settled. A code of laws has been drawn up, and agreed to, by the Engineers and managing directors present at these meetings, which is revised and enlarged from time to time, according to the requirements. These rules express the decided opinion of the associated body, upon all the points which are usually involved in the construction and working of railways, and are adopted by all concerned, as the standard source of guidance and instruction in such matters. It may here be proper, before passing on to the consideration of the engineering points involved in the present subject, to state that Germany at the close of the year 1861, had, in addition to railways, about 143 miles of tramways, constructed at an average cost of £3,200 per mile.

The battle of the gauges can scarcely be said to have been fought in Germany, or, if so, it was conducted with almost all the energy on one side; as, early in the movement, the gauge of 4 feet 8½ inches came off victorious, and the line from Mannheim to Heidelberg, which represented the opposing interest, having been laid to a medium width of 5 feet 3 inches between the rails, after struggling along for some time in its unsocial loneliness, was obliged to yield under the pressure of public opinion and the inconvenience arising from a break of gauge, and was altered to the ordinary width of 4 feet 8½ inches, which is now the universal gauge of the country.[1] The width between the ways on a double line of railway is usually fixed at 2 metres between the centres of the rails, or 6 feet 4½ inches in the clear. At stations, this allowance is generally greatly increased.

With regard to curves and gradients the rules laid down are,—First, The radius of curvature shall, if possible, not be less than 3,600 feet on level land, nor than 2,000 feet in hilly districts, except in particular instances, when it may be necessary to reduce it to 1,200 feet. This latter is to form, as a general rule, the minimum rate of curve on railways in mountainous countries, to be diminished in exceptional cases, where necessary, to 600 feet, but never less.

Secondly, The general scale of maximum gradients admissible on railways is, 1 in 200 in level districts, 1 in 100 among hills, and 1 in 40 on mountain lines.

As examples of sharp curves upon works already executed may be noticed:—One of 570 feet, and another of 590 feet radius on the Baden State Railways; two curves of 618 feet radius on the railway from Magdeburg to Wittenberg, and a similar minimum radius on the railway from Breslau to Schweidnitz; one of 560 feet and several of 622 feet radius occurring on the passage of the Alps, on the line from Vienna to Trieste; the viaduct approach to the Cologne bridge, on the left bank of the Rhine, is on a curve of 618 feet radius; a curve of 780 feet radius on the line between Passau and the Austrian frontier, and of 824 feet as the minimum radius of curvature on the Main Weser Railway from Frankfort-on-Maine to Hesse Cassel; besides numerous other curves of importance on existing lines.

The increased power of locomotive engines has introduced into practice a severer character of ruling gradients than was formerly contemplated. On main lines, when practicable, 1 in 100 is now generally adopted as the maximum rate of inclination. In many instances, where the districts traversed are very level, the gradients are much easier than this; but on the other hand, Germany has ample proofs of having approached the limits recognised at present as suitable for the working of locomotives, in gradients of the steepest description, which are not confined to one State, or locality, but are to be found in both north and south. As an illustration of this statement it will suffice to instance some of the most important cases:—Between the stations of Erkrath and Hochdahl, on the railway from Düsseldorf to Elberfeld, there occurs a continuous incline of 1 in 30 for a distance of 8,038 feet, or upwards of 1½ mile. This was originally worked by stationary engines and a long endless rope. In 1841 the plan was altered, and the trains in opposite directions arranged so as always to meet at this point, and the weight of the descending train was made use of in helping to draw the other up, by means of a rope attached to both trains, and passed round rollers at the top of the incline. The difficulties arising from the necessity for the meeting of trains brought about another modification in the system of working, which is that now in use. A pilot engine is always ready with steam up to assist the ascending trains, which it does by acting as a counterpoise attached to the upper portion of the rope, in the same capacity as was formerly fulfilled by the descending train. This latter now always passes down without being attached to the rope, and under the control of powerful breaks, and by these means the inconvenience to the traffic, from being compelled to depend upon meeting trains, has been removed. The Aix-la-Chapelle incline of 1 in 38, for a length of 6,844 feet, stands next on the list. It begins immediately on leaving the station, and rises westwards towards the Belgian frontier. It, also, was intended to be worked by stationary engines; but a tank engine, with three pairs of coupled wheels of small diameter, now answers the purpose, by pushing the train from behind, up to the station at the level on the summit, where an ordinary engine is in waiting to take the train on. Several gradients of 1 in 40 and 1 in 45 were adopted on the Semmering Railway, of which a particular account has already been brought before the Institution.[1] An incline of 1 in 40, for a distance of 17,680 feet, or upwards of 3⅓ miles, upon the Bavarian State Railway, from Augsburg to Hof, serves to surmount the watershed between the rivers Maine and Saale, near the village of Neuenmarkt. The short Schneeberg branch line in Saxony has gradients of 1 in 40, and the total ascent which it makes averages at the rate of 1 in 48. The passage of the Swabian Alps, between Geislingen and Amstetten, on the Würtemberg State Railway, from Stuttgart to Ulm, is accomplished by means of an incline of 1 in 45, 16,720 feet long, or 3⅙ miles. There is a gradient of 1 in 45, for a length of about 1,800 feet, at Viennenburg, on the Brunswick State Railway, from Wolfenbuttel to Harzburg. On the railway from Bamberg to Asschafenburg, there is a gradient of 1 in 50, extending over 4⅔ miles. The same rate of inclination occurs on the line from Breslau to Schweidnitz, and also between Eisenach and Coburg, near the former place, on the Werra Railway; the length of the gradient being 3 miles.

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[1] To this must be mentioned as an exception the branch from Lambach to Gmünden, 16 miles in length, already described.

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[1] *Vide* "Minutes of Proceedings Inst. C.E," vol. xv., p. 349.—"On Steep Gradients of Railways, &c.," by C. R. Drysdale, in which an account is given of this line, and of the mode of working it.

The Semmering Railway, already alluded to, is one of the most remarkable instances of a combination of heavy gradients with sharp curves. This line, which is in reality but a section of the Southern Railway of Austria, from Vienna to Trieste, extends from the station of Gloggnitz to that of Mürzzuschlag, a distance of 25·44 miles, or more exactly 134,300 feet. In considering the nature of the gradients, it may be divided into three sections as follows:—

1st	from Gloggnitz to Payerbach	20,815 feet.
2nd	„ Payerbach to the Semmering summit . .	64,033 „
3rd	„ The summit to Mürzzuschlag . . .	49,452 „
	Total	134,300 „

In going southwards the rise is gradual until Payerbach is reached, the maximum inclination being 1 in 100. From thence, until attaining the summit level, which gives its name to the pass, the gradients and curves are of the heaviest and sharpest character, in order to overcome the various natural obstacles in the way. On this middle section several gradients of 1 in 40, one of them, the longest on the line, being 11,618 feet, or 2⅕ miles, and curves of 622 feet radius occur. From the summit to Mürzzuschlag station the descent is rapid and steep, the heaviest rate being 1 in 41·4. The difference of level between Gloggnitz and the summit is 1,506 feet; the height of the latter being 2,937 feet above the sea-level; and the fall from thence to Mürzzuschlag on the south side is 714½ feet. The nature of the inclines, and their effect upon the working of the line, will be best understood by referring to the following tabular statement:—

LIST OF GRADIENTS.

From 1 in 40 to 1 in 50 . .	61	per cent. of the entire length.
„ 1 in 51 to 1 in 70 . .	9	„ „
„ 1 in 71 to 1 in 100 . .	8	„ „
„ 1 in 101 to 1 in 120 . .	15	„ „
„ 1 in 121 to 1 in 500 . .	6	„ „
Level	1	
	100	„ „

The curves under 1,000 feet radius are,

1	Curve of	560	feet radius.
29	„	622	„
1	„	746	„
2	„	871	„
1	„	902	„
34	„	933	„

The proportion of straight line and curves stands thus,—

Curve of 560 . . .	feet radius .	0¾	per cent.	of the entire length.
„ 622	„	15¼	„	„
„ 623 to 1244	„	26	„	„
„ 1245 to 1867	„	6	„	„
„ over 1867	„	2	„	„
Straight lines		50	„	„
		100		

Several of the curves of 622 feet radius occur upon inclines of 1 in 45.

There are fifteen tunnels on this work, of the aggregate length of 14,867 feet. The longest is that through the summit, called the Semmering, which is 4,695 feet. The next, in point of length, is one of 2,280 feet.

The viaducts, of which there are sixteen, are built of masonry and brickwork, and are principally composed of semicircular arches, varying in span from about 25 feet to 65⅓ feet. The longest of these works is 614 feet, and the four which attain to the greatest height, from 119 to 150 feet, consist of two rows of arches, one above the other; the lower of which tends to strengthen the piers and add stability to the structure. Many of the viaducts are placed on curves of 622 feet and 933 feet radius, and on gradients of 1 in 45.

The permanent way consists of flat-based rails, weighing 76⅓ lbs. per yard, resting on cross-sleepers, laid 3 feet 1⅓ inch apart from centre to centre, which in their turn are supported by longitudinal timbers, into which they are let, and held firmly in place by small angular iron brackets. The rails are 4$\frac{6}{10}$ inches in depth, have a similar width of base, with a head 2¼ inches broad, and a thickness of $\frac{17}{20}$ inch for the central web; their usual length being 18 feet 8 inches. The joints are made fast by fish plates, with four screw-bolts in the usual manner; underneath are placed wrought-iron chair-plates, to prevent the working of the ends of the rails into the sleepers. A similar plate, but of smaller dimensions, is interposed between the base of the rail and the timber at each of the intermediate bearings. The joint sleepers are 12½ inches wide, by 6¼ inches thick, and the intermediate sleepers are 9 inches by 6¼ inches. The ballast consists of a lower course of angular broken stone of large dimensions, laid with the hand, on which rest smaller broken stone and gravel. Its depth at the centre of the gauge, measured from the surface of the 'boxing,' which reaches to within 2 inches of the rail level, is 2 feet 4 inches, and the width to which it extends outside the rails is 4 feet 6 inches on embankments, and 3 feet 9 inches in cuttings.

The engines used for working the line are of a peculiar description, the result of a prize offered by the Government, for the best locomotive to take a given load up the inclines, with a fixed minimum velocity. The engine and tender are in one, and rest upon five pairs of wheels; the three leading pairs are coupled together, and attached to axles fixed at right angles to the axis of the boiler. The other two axles are placed, one in front of the fire-box, and the other under the tender, and are attached to a movable carriage, or frame, which admits of the wheels suiting themselves to the nature of the sharp curves to be traversed. The following statement shows the comparison between the passenger and goods engines on this line, and their principal average dimensions :—

—	Passenger Engine.	Goods Engine.
	Ft. In.	Ft. In. Ft. In.
Diameter of Driving-wheels (3 pairs coupled)	4 3	3 4 to 3 6
Ditto of uncoupled wheels (2 pairs) . .	3 1	3 4 to 3 6
Ditto of Cylinder	1 6⅔	1 7 to 1 7⅓
Length of Stroke of Piston	2 0	2 ft. 0 in.
Diameter of Boiler (mean)	4 3	4 3
Length of ditto	15 6	15 6
Number of Tubes 2 inches diameter . .	No. 191	No. 191
Average Heating Surface, in square feet	1,694	1,694
Maximum pressure of Steam in Boiler, per square inch	100 lbs.	100 lbs.
Thickness of Iron Plates in Boiler . .	$\frac{6}{16}$ in.	$\frac{6}{16}$ in.
Distance apart of centres of extreme coupled wheels	ft. in. 8 11½	ft. in. 7 6
Ditto, ditto, uncoupled, about. . . .	8 0	8 0
Total length of Engine from buffer to buffer	37 11	ft. in. ft. in. 34 9 to 35 10
Total weight of Engine on 5 pairs of wheels (empty)	44 tons.	48 to 50 tons.
Adhesive weight of Engine on 3 pairs of coupled wheels, loaded with an average supply of water, &c.	39 tons.	38 to 41 tons.

The cost of one such engine was about £3,500.

The experience derived from the working of this line goes to show, that one of the goods engines can ascend the inclines of 1 in 40 at the rate of 9½ miles per hour, taking with it a train whose gross weight varies from about 100 tons to 165 tons, according to the state of the rails and the weather at the time. The normal rate of speed fixed is as follows :—

	Ascending.		Descending.	
For Express Trains . . .	14¼ miles per hour	. .	16½ miles per hour.	
„ Ordinary Passenger ditto	11⅜ „ „		14¼ „ „	
„ Military Transport and Goods Trains . . .	9½ „ „		9½ „ „	

In case of a train being late, any one of the foregoing speeds may be increased, if necessary, by $4\frac{7}{10}$ miles per hour. The maximum number of trains which have passed over the line in one day occurred during the Italian war, and amounted to seventy-two, counting both ways. The ordinary average daily number of trains is twenty-seven, with from seven to eight carriages in each train. The actual works of construction on the Semmering Railway were begun towards the close of the year 1848, and the line was opened for public traffic on the 17th July, 1854. Previous to this, however, during the year 1853, rails were laid throughout the entire length of the line, and goods were transported over it by means of locomotives. The line, which is laid with a double way throughout, cost £98,270 per mile.

Passing on to the next point for consideration, that of earthworks, it appears to be a general, although not a universal, plan, in the case of all main lines, to prepare the earthworks and masonry for a double way from the first, but not to lay the second line of rails, until the success of the undertaking makes itself apparent, and the requirements of the traffic demand the additional way. Some of the heaviest earthworks executed have been :—An embankment on the Southern State Railway of Bavaria, from Augsburg to Lindau, its greatest height being 172 feet, width at formation 33½ feet, and length 1,675 feet, requiring upwards of 2,900,000 cubic yards of material to make it up. On the same line also occur embankments of great importance, two of which are respectively 84 feet and 72 feet high. On the railway from Augsburg to Ulm, there is a cutting 2,390 feet long, and reaching to a depth of 90 feet; also an embankment 53 feet high, and 5,755 feet in length. Between Elberfeld and Dortmund occurs an excavation 86 feet deep, and upwards of 1¼ mile long; and on the same line there is an embankment 120 feet in height, with a length of 1,600 feet. Embankments from 75 feet to 130 feet high are to be found on the Westphalian railways. On the Bavarian State line, from Bamberg to Aschaffenburg, there is an embankment 100 feet in height at the highest point, and 1,743 feet long; besides two cuttings measuring in depth, the one 84 feet, and the other 71 feet, their respective lengths being 3,254 feet and 2,297 feet.

With regard to tunnels, the first executed in Germany was one 1,678 feet long, on the Leipzig and Dresden Railway. Besides the summit tunnel, 4,695 feet in length, on the Semmering Railway, already mentioned, there are many others worthy of notice, among which some of the most important are :—

A Tunnel 5,359 feet long at Königsdorf between Cologne and the Belgian frontier.
„ 4,419 „ „ Heiligenberg between Ludwigshafen and Bexbach.
„ 3,600 „ on the Saarbruck, Trier and Luxemberg Railway.
„ 3,235 „ „ Railway from Gerstungen to Carlshafen.

and a tunnel 3,037 feet long through the Schwarzkopf between Bamberg and Aschaffenburg.

This brings the subject to one of the most interesting of its subdivisions, that of viaducts and bridges, which it is proposed to treat under two separate headings,—First, Bridges composed altogether of masonry, and, secondly, Iron Bridges. There are instances of large timber bridges, such as those over the branches of the Danube, at Vienna, on the "Emperor Ferdinand's Northern Railway," and that over the Elbe, at Magdeburg, whose superstructure only is of wood; but as these are cases of works executed in past years, and it being now laid down as a maxim by German Engineers, that timber is not to be used in railway bridges, it becomes unnecessary to devote space to the consideration of such works. To explain more fully these somewhat anticipatory remarks, it may be well to introduce here, the views of the Associated Railway Directors on bridge building, as expressed in their code of rules. These are—I. For bridges, arches of stone, or good bricks, are preferable to every other description of structure, except in cases which require very oblique bridges. II. Timber bridges are inadmissible. III. When iron bridges are made use of, the portion of the superstructure which sustains the roadway shall consist of either wrought, or rolled iron. Thus cast-iron bridges, as well as timber ones, are removed from the field of investigation. The former by negation, and the latter by direct condemnation.

Germany abounds in fine examples of stone viaducts and bridges of imposing dimensions and extent. It will be sufficient to adduce a few instances in addition to those already casually noticed, as occurring on the Semmering Railway. At the head of these stands the viaduct over the Goeltzsch Valley, on the railway from Leipzig to Hof. It consists of one central span of 93 feet, twenty-three spans of 46 feet in the clear, four spans of 39 feet, and two spans of 21 feet, one on each side of the large span through what may be called the abutment piers. Its greatest height is 255 feet, and extreme length 1,882 feet. The 93 feet opening has two arches one above the other, and on either side of it rise four rows of arches decreasing to one row at the ends. These additional arches are for the purpose of strengthening and supporting the piers, which carry the upper or main arches. All those in the upper tier are semicircular in form, as is also the lower arch of the central span, while the others are segmental.

There is also another fine viaduct over the Elser Valley, on the same railway. It is formed of six semicircular arches of 93 feet span in the clear, three openings of 20 feet, and one of 15 feet. Two of the lesser openings have four tiers of arches in height, and occur on both sides of the arch which spans the deepest part of the valley. Two of the 93 feet widths are strengthened by a lower row of semicircular arches, and two others by means of connecting walls. This viaduct is, at its greatest height, 223 feet above the stream, and is 914 feet long.

The Neisse Viaduct on the branch railway from Kohlfurth to Görlitz, in Prussia, consists of one row of semicircular arches, thirty in number, of which three spans have a clear width of 73 feet 1 inch, three of 61 feet 9 inches, five of 41 feet 2 inches, and eighteen of 30 feet 10¾ inches. Its greatest height is 123 feet above low water, and its length, inclusive of abutments, 1,550 feet. This viaduct carries a double line of railway, and occupied about three years and a half in its construction, having been begun during the spring of 1844, and finished in the autumn of 1847. The masonry composing it amounted to 1,173,200 cubic feet.

The result of a series of experiments, for the purpose of ascertaining the best description of concrete to be placed round the foundations of the river piers, gave the proportions most suitable for yielding a quick setting, hard concrete, at

22	per cent.	of cement
22	„ „	of sand
56	„ „	of small broken stone (2 inches diameter)
100		

A stone bridge over the Elbe, on the Junction Railway, at Dresden, is well worthy of notice. It consists of twelve basket-handle arches of 93 feet span each. The width of the roadway is 50 feet, one half of which is applied to the purposes of an ordinary road, and the other half to those of the railway. Its height is 37 feet above the river at summer level. One approach to this bridge is formed by a viaduct of forty-four arches of lesser span.

A bridge over the Roeder, on the railway from Dresden to Görlitz, consists of one arch 148 feet 8 inches wide.

As a sample of an ordinary river bridge of handsome, although not very extensive, proportions, may be mentioned that over the Neckar, on the railway from Frankfort-on-Maine to Heidelberg. It is divided into seven equal spans of 88 feet 7 inches each, and carries a double line of permanent way at about 35 feet above the ordinary water level. Its building occupied from 1844 to 1848. The form of the arch is segmental, with a versed sine equal to one-eighth of the span. The thickness of the piers at the springing is 10 feet 4 inches, or between one-eighth and one-ninth of the span. That of the abutments is 39 feet 4 inches. The width of the bridge between the outside faces of the masonry is 31 feet 6 inches, and the depth of the key-stone is 3 feet 11¼ inches (1·2 metre). Comparing this latter quantity with the results to be derived from the different rules of eminent French authorities on bridge building, it appears that the depth of the key in the case of the Neckar bridge is somewhat over the minimum thickness required, both by Desjardin's formula and by that of Gauthey. On the other hand, it is so out of proportion with the huge thickness obtained from the method of Perronet, as to prove the total unfitness of this system for calculating cases similar to the one in question. Thus—

By Desjardin's formula for an arc of a circle = 40°,

$$E = 0{\cdot}02\,r + 0{\cdot}30 \text{ metre},$$

where E = the thickness of the key, and r = the radius of curvature of the intrados in metres, which in the present instance is approximately 42 metres. Supplying this value, the expression becomes

$$E = 0{\cdot}02 \times 42 + 0{\cdot}30 \text{ metre} = 1{\cdot}14 \text{ metre}.$$

By Gauthey's rule for spans of 16–32 metres

$$D = \frac{1}{24} S$$

where D = the depth of the key, and S the span in metres, and S being 27 metres,

$$D = \frac{27}{24} = 1{\cdot}125 \text{ metre};$$

whereas in testing the matter by the method of Perronet it stands

$$E = \frac{1}{24} D + 0{\cdot}325 \text{ metre} - \frac{1}{144} D,$$

in which E = the depth of the key, D = the span, in the case of semicircular arches, but in segmental or elliptical ones, D = double the radius of the intrados at the crown. Reducing this equation to a simpler form, it becomes

$$E = \frac{5}{144} D + 0{\cdot}325 \text{ metre},$$

and supplying for D its value, 84 metres,

$$E = \frac{5}{144} \times 84 + 0{\cdot}325 \text{ metre} = 3{\cdot}241 \text{ metres},$$

or nearly three times as great as the thickness required by Gauthey's rule.

By comparing the practical example with the three calculated results, the following is obtained:—

metre.
The Neckar bridge, as actually built, has a depth of key = 1·200
Ditto, according to Desjardin's formula, requires ditto . = 1·140
Ditto, ditto, Gauthey's ditto, ditto . . . . . = 1·125
Ditto, ditto, Perronet's ditto, ditto. . . . . . = 3·241

In the case of wrought-iron bridges the arrangement most usually adopted, when the spans are wide, is that of a lattice construction, in some one of its various modifications.

One of the earliest examples of importance is that of the bridge over the river Kinzig, at Offenburg, on the Baden State Railway. It is built for a double line of railway, with two projecting footpaths on the outside, and consists of three main girders, one on each side, and one in the centre between the ways. There is but one span, its width being 206 feet 8 inches in the clear. The depth of the girders is 20 feet 7 inches, and they rest 13 feet 3 inches on each abutment. The top and bottom cross sectional areas of all three girders are the same, consisting of three thicknesses of iron laid one over the other, and forming together a plate $1\frac{7}{16}$ inch thick and 13 inches wide; in addition to which there are four angle irons $4\frac{3}{4}$ inches by $4\frac{3}{4}$ inches by $\frac{17}{32}$ inch to $\frac{21}{32}$ inch thick, and one vertical bar, $5\frac{9}{16}$ inches by $\frac{19}{32}$ inch, on the outside, running along the centre of the horizontal plates which form the top and bottom portions of the girder, to which it is attached by two of the angle irons, the other two serving to join the flanges to the bars which form the central web. This latter is composed of lattice-work, which, in the case of the two outside girders, is formed with two sets of bars, $4\frac{1}{6}$ inches by $\frac{13}{16}$ inch, crossing each other at right angles, and inclined to the top and bottom at an angle of 45°, the distances of the crossings apart being 1 foot $5\frac{11}{16}$ inches between the centres of the rivets measured along the bars. The central rib of the middle girder, between the ways, is stronger than that of the outside ones, inasmuch as it consists of three sets of bars, two of which are $\frac{5}{8}$ inch thick and one $1\frac{5}{16}$ inch, all having the same width as the other lattice bars. Along the whole length of each central rib there are two horizontal rows, formed of double rails of the bridge pattern, one on the inside and the other on the outside, and riveted to the lattice work. These rows occur at distances of 3 feet $11\frac{1}{4}$ inches and 7 feet $2\frac{1}{2}$ inches respectively below the top and above the bottom of the girders. The roadway inside and the projecting footpaths are supported by transverse trusses, at intervals of 6 feet 3 inches apart, formed of ordinary flat-based rails, and the entire bridge is connected above and below by a system of cross and diagonal braces. The clear width between the outside and the central girders is 12 feet 8 inches. The abutments are surmounted by handsome ashlar portals in red sandstone. The weight of cast iron in the bed plates is 23 tons, and of wrought iron about 322 tons, distributed thus:—

Weight of central girder	= about	92	Tons.
Ditto, two side girders (together)	„	148	„
Ditto, cross girders and lower braces . . .	„	55	„
Ditto, upper connecting bars	„	20	„
Ditto, handrail for footpaths	„	7	„
Total wrought iron in bridge . .	„	322	Tons.

From this short description it appears, that the arrangement of the material is not a judicious one, considering the nature of the strains arising from the weight of the bridge itself and any superimposed load, since,—I. the dimensions of the ironwork are uniform throughout the length of the span.—II. Although a stronger lattice construction is adopted in the case of the central girder, still its top and bottom sections are of similar dimensions to the outside ones; and—III. the cross sectional area of the iron has not been properly proportioned to its different powers to resist compression and extension, where these forces act.

Passing on from the consideration of the first of these undertakings on an extensive scale, the largest work of the kind yet executed in Germany naturally presents itself. This is the bridge on the Eastern Railway of Prussia, over the river Vistula, at Dirschau, consisting of six spans, each 397 feet $5\frac{2}{3}$ inches in the clear. The depth of the girders is 38 feet $9\frac{1}{3}$ inches and the height of their underside, above the ordinary water level, is 34 feet.

The arrangement is for a single line of railway, but the width is 20 feet $7\frac{1}{8}$ inches in the clear, and the rails are laid along the centre, so that sufficient space is left on each side for ordinary traffic, to which the bridge is open except on the approach of trains. In addition to this, pathways for foot-passengers are suspended on cantilevers on both sides. The ironwork of each two spans is distinct in itself, being fixed on the pier at its centre, and moving on rollers at both ends. The system on which the iron work is constructed is that of two girders, one on either side of the roadway, held together above and below by a series of diagonal and transverse braces, in both the vertical and the horizontal planes. The girder top consists of four horizontal tiers of boiler-plate 2 feet $6\frac{9}{10}$ inches wide, placed one above the other, at distances of 2 feet apart, and made fast to a central vertical web, by means of angle irons; and similar angle irons are riveted below each of these horizontal plates along their outside edges. The bottom section consists of an ordinary boiler-plate girder 4 feet $1\frac{4}{10}$ inch deep, with two flanges 4 feet 6 inches wide; the bottom of which has two thicknesses of plates, and angle irons along the outside edges, while the top consists of a single plate. The solid top and bottom sections of the girders are connected by means of a lattice frame, consisting of two rows of bars inclined at 45° to the horizontal, and crossing each other at right angles, at distances of 1 foot 6½ inches between the rivets, measured along the bars. This is again strengthened by double angle irons 5½ inches by 4½ inches, and 1½ inch by ½ inch thick respectively, arranged vertically, one inside and the other outside, and riveted to the lattice at horizontal distances of 6 feet 2⅛ inches apart. At these points also are attached the cross-girders, of lattice construction, which support the roadway at a height of 6 feet 2⅛ inches above the underside of bridge. The thickness of the boiler plates in the top and bottom sections is about ½ inch at the centre of the span. The lattice bars vary from a width of 4⅛ inches at the centre to 5⅛ inches at the sides, and are ½ inch thick at the centre of the span, increasing to ⅞ inch at the moveable end, which rests on rollers, and to 1 inch on the piers where the girders are fixed. Over all bearings the vertical angle irons are only half the normal distance apart, and the ends of the girders are further stiffened by solid plates. At the bearings furnished with rollers—that is to say, both abutments and piers Nos. 2 and 4—the breadth and depth of the top and the bottom sections of the girders remain the same as at the centre of openings; whereas in the case of piers Nos. 1, 3 and 5, where the bearings rest immoveably, the top is increased to 4 feet 4 inches in width, and all its horizontal plates are laid in double thicknesses of iron, while the bottom section, although retaining its regular width, is strengthened by doubling its depth by means of two corbels attached to the lower flange, the furthest of which projects about 40 feet from the face of the masonry and the other 8 feet 6 inches. The whole of the material in the superstructure was carefully proportioned to the nature of the strains to which it would be exposed. The foundations for the piers were prepared by driving a number of bearing piles into the sand, at the rate of one to every 18⅓ square feet. The whole space was enclosed by a row of sheet-piling timbers 12 inches square, driven close together and reaching to a height of upwards of 10 feet above the tops of the bearing-piles. The area thus formed, being filled up level with the tops of the surrounding piles with concrete, furnished a bed 10 feet in thickness on which the masonry rests. The foundations of the abutments were treated somewhat similarly to those of the piers, but they are not so deep.

The projections of the piers both up and down stream present sharp vertical arrises, or nearly so, from the water edge to the underside of the roadway. The facework masonry consists principally of basalt, with a small proportion of granite ashlar up to above ordinary water level. Above this hard sandstone is used, but only in the body of the piers. In the cutwaters the basalt masonry is continued for their full height. The blocks immediately under the ends of the girders are also of basalt. The backing and filling in is formed of hard burned bricks, and partly with ashlar, where greater strength is required, the whole being laid in hydraulic mortar. The piers are 32 feet 11 inches wide at the underside of the girders and 82 feet long in the direction of the stream. On each of the piers rise two circular towers, one on either side of the roadway, whose battlements reach to nearly 43 feet above the top of the girders. The abutments are surmounted by massive rectangular towers and a handsome connecting portal. The towers are all built with yellowish-white bricks, ornamented glazed ones of a purple colour being used in some of the mouldings. The copings and principal dressings are of gray sandstone.

The general effect produced by this bridge, when seen from a distance, is very fine. The great depth of the girders reduced to some extent, however, the impression which would otherwise arise from the magnitude of the spans, apparently diminishing them to much within their real limits.

There is one point in which the Author thinks the ornamenting of this beautiful bridge is deficient. That is the crowded state of the relief over the pointed arch of the Dirschau portal, in which the field is far too small for the subject, and the upper moulding is brought down so close to the head of the principal figure, as to give the appearance of the design having been originally intended for a totally different position to the one it now occupies.

About 10 miles nearer to Königsberg than Dirschau, and also on the Eastern Railway of Prussia, occurs the Marienburg Bridge, over the Nogat, which is in reality another arm of the river Vistula. The bridge consists of two spans of 321 feet 3¼ inches each, and two segmental arches in masonry of 53 feet 6½ inches in width, one at either end of the bridge. The roadway is for a single way, with a footpath on both sides, and is arranged for ordinary traffic similarly to the Dirschau Bridge. The distribution of the iron in the superstructure is, however, altogether different. The Nogat Bridge may be described as a compound, the whole forming one girder, or tube, about 25 feet in depth, of which the top and bottom are composed of ordinary boiler plates, and the sides of lattice-work, similar in principle to that already described. The cross girders which support the rails are of lattice work 24¾ inches in depth, and are placed at distances of 6 feet 2⅛ inches apart. At these same intervals, attached to the upper portion of the vertical L irons, within 6 inches of the top plates, are transverse bars, something in form like the letter Z, stretching from the lattice on one side of the roadway to that on the other.

These ribs, as well as the keelsons below, are more securely made fast to the vertical rods by gusset pieces, which tend to stiffen the bridge laterally. In the space, 6 inches, thus left between the cross ties and the covering plates, six iron bars, also Z shaped, run longitudinally for the whole length of the girder, giving the top the appearance of a cellular form of construction in cross section.

As regards the nature of the foundations and the character of the masonry, they are similar to those at Dirschau. The towers on the central pier are, however, rectangular in form, instead of round as in the latter case.

Both bridges have arrangements for mounting cannon, and other military precautions, at their ends.

The next example selected is that of the bridge over the Rhine at Cologne. It consists of four river spans each $322\frac{3}{10}$ feet in the clear, and two equal land openings of 64 feet $10\frac{2}{3}$ inches in width over the wharf and street on the left bank of the river. Two distinct bridges, one 24 feet $8\frac{1}{3}$ inches in the clear carrying a double line of railway, and the other 27 feet $9\frac{1}{2}$ inches inside width, for the purposes of ordinary traffic, are placed parallel to each other, and close together on the same piers; that on the down stream side being used by the railway. The depth of the girders for the four large spans is 27 feet $9\frac{1}{2}$ inches, and they are formed in two separate lengths each extending across two openings. The clear height above low water is 50 feet.

The railway bridge is formed of lattice girders, double on each side. The cross section of the top of one side is that of two T's placed one after the other, and close together, thus **TT**, and the bottom has a similar form, but reversed. The lattice frames which connect them are 2 feet apart, and are tied together and stiffened by diagonal braces, placed vertically at every 5 feet $1\frac{3}{4}$ inch. At the same intervals there are vertical angle irons, to strengthen the lattice, and keelsons to carry the roadway. Transverse angle irons and diagonal bars above are attached at every second one of these points. The lattice bars cross each other at distances of 2 feet $6\frac{7}{8}$. inches apart measured diagonally. They are about $3\frac{10}{16}$ inches by $\frac{1}{2}$ inch at the centre of spans, increasing to $4\frac{3}{16}$ inches by $\frac{29}{32}$ inch, at the ends resting on rollers, and to $5\frac{9}{16}$ inches by $1\frac{3}{10}$ inch at the fixed bearings.

The principle of construction of the bridge for ordinary traffic is similar to that for the railway, with the exception that the top and bottom sections are in shape that of a single **T**, and the sides consist of a single lattice instead of double frames. Every second vertical rod is also composed of two angle irons, instead of one, laid together so as somewhat to resemble the letter **E**. The total weight of iron in both bridges is about 4,600 tons.

The foundations were formed of concrete, laid on the solid natural bed of gravel, which approaches close to the surface in the neighbourhood of Cologne. The ashlar masonry consists of basalt and sandstone, the former being used in the facework up to the underside of the girders, and where the greatest strength is required. The piers terminate in sharp upright cutwaters; their form on the down stream side being similar to the upper. Their thickness is 20 feet 7 inches at the level of the girders. The ornamental portion of the design only includes towers, which are rectangular in shape, on the centre pier, and on both abutments.

The approach to the bridge from the Central Railway Station in Cologne is effected by means of a viaduct of segmental arches, in brickwork, upon a sharp curve, whose radius, as already mentioned, is 618 feet.

The next case to be alluded to is that of the bridge across the Rhine, at Kehl, close to Strasburg. In cross section this bridge is somewhat similar to the Kinzig one, comprising two lines of rails with a lattice girder on either side and one in the middle, all connected together, and two footpaths supported on the outsides. The main portion of the bridge is that to which the lattice system is applied, and consists of three spans of 184 feet $8\frac{3}{4}$ inches each. In addition to this there are two swing bridges of 210 feet diameter, with solid wrought-iron plate sides, and opening a clear width of 85 feet 3 inches on each side of the river for military purposes rather than those of navigation. The depth of the girders for the three principal spans is 19 feet $10\frac{1}{2}$ inches, and the clear roadway in each case is 13 feet 9 inches. The lattice bars are inclined at an angle of 45° to the horizontal, and form a net work, the open spaces of which measure about 3 feet diagonally. They are secured at their crossings by two rivets. The top and bottom sections of all three girders are in form that of the letter T; but they, as well as all other parts, are carefully arranged, so as to insure uniform strength for the bridge throughout, in proportion to the effect produced upon it by a load. The keelsons occur at intervals of $3\frac{1}{17}$ feet, and are in direct contact with the rails, which are riveted to them. The lattice work is stiffened by vertical angle irons, fixed double on both sides, at distances of 9 feet $6\frac{1}{6}$ inches. The iron work in the whole of the three openings is in one length, and is tied together above and below by a system of transverse and diagonal rods. The entire weight of the wrought iron in the superstruction is 984 tons, or at the rate of 328 tons per span of 184 feet $8\frac{3}{4}$ inches for a double line of railway. All the piers are surmounted by handsome Gothic ornamental work in cast iron. Great difficulty was experienced with the foundations of the bridge, owing to the nature of the stratum of shifting sand which underlies the bed of the river at this point. They were eventually sunk to a depth of about 66 feet below the lowest water, by means of wrought iron cylinders, in which the masonry was built and undermined; the method adopted being that of compressed air. The operation of sinking the foundations progressed at the rate of about 20 inches per day of twenty-four hours.

In addition to these two bridges there is another now in process of erection over the Rhine, at Mayence, which is expected to be completed during the autumn of the present year. It consists of the following spans:—

		Feet.	In.
4 River openings of 331 feet 8⅓ inches each .	=	1,326	9⅓
6 Flood " 109 " 11 "	=	659	6
2 " " 82 " 0 "	=	164	0
20 " " 49 " 2½ "	=	984	2
32 spans in all, yielding a clear waterway of lineal measure.		3,134	5⅓

The total distance between the abutments is 3,372½ feet, and the heights of the underside of the girders above low water is to be 45⅓ feet. The foundations are, like those of the Cologne Bridge, formed of concrete. The face masonry consists of red sandstone and ashlar, formed from the granite boulders found in the neighbourhood. The ironwork in the superstructure, which is for a single way, is very similarly arranged to that in the Saltash Bridge, modified in some particulars as to the cross section, and the form in which the material is applied, according to what is known in Germany as the system of Professor Pauli, of Munich, which gives a rectangular top to the beam instead of an oval one. As a good example of Herr Pauli's system may be mentioned the bridge over the Isar, at Grosshesselohe, on the railway from Munich to Salzburg. It has four spans,—two of 191½ feet, and two of 95¾ feet, at a height of 101½ feet above low water.

The Eastern Railway of Bavaria has also some fine lattice bridges, such as that over the Danube at Regensburg, having five river spans of 153 feet 2½ inches each, with iron superstructure for single way, and fifteen flood openings of segmental arches in masonry each 47 feet 10½ inches wide, of which three are on the left and twelve on the right bank of the river. The height of the underside of the girders is about 33 feet above low water. The bridge was finished in 1859, and the weight of the ironwork in the five openings is 563 tons, or 112⅗ tons per span. On the same railway, at the town of Passau, there is a bridge over the river Inn, with one span of 296 feet 10 inches measured on the skew, the angle between the axis of the railway and the direction of the stream being 71°; adjoining this opening there are six stone arches, five of 47 feet in width on the left bank of the river, and one of 38 feet 3½ inches on the right. The level of the rails is about 46 feet above low water, and the weight of iron in the bridge is 347 tons, for a single line of rails.

These few examples are sufficient for the purpose of illustrating the progress made in Germany in the construction of iron bridges on a large scale, and complete this portion of the subject under consideration.

Directing attention to the next branch, that of the permanent way, it appears that about seven-eighths of the rails in use are of the broad base or contractors' pattern; the remaining one-eighth being composed chiefly of chair rails, with a small proportion of the bridge-shaped ones. Fishplates, made fast with four screw-bolts, are now almost universally adopted, for connecting the ends of the rails, and the joints are always supported by a sleeper, generally 12 inches by 6 inches, a wrought-iron chair-plate being interposed between the rail and the timber. The modern English system, of leaving the joint free without any sleeper under it, has hitherto met with but little favour from German Engineers. A trial of this arrangement has, however, lately been made, on a short length of the railway from Frankfort-on-Maine to Heidelberg, and the result has been so satisfactory, that it is intended to lay the entire permanent way of the new line about to be constructed from Gustavsburg (opposite Mayence) to Frankfort, on this plan.

With regard to the size of rails, the rule laid down is that they shall not be less than 4½ inches in height by 2¼ inches in width of head, and that their surface shall be curved to a radius of from 5 inches to 7 inches. The general weight of rails now adopted varies from about 66 lbs. to 76 lbs. per yard, both these limits being passed in a higher and lower direction according to local requirements.

The following Table of the dimensions and weights of some of the principal broad base, or contractors', rails in use on various lines will afford interesting information on the subject:—

—	Weight per Yard.	Width of Head.	Width of Base.	Thickness of Central Web.	Height of Rail.
	lbs.	inches.	inches.	Inch.	inches.
Dortmund and Soesto Railway. .	66·	2¼	3·86	0·55	4·65
Louise of Hesse ditto	68·25	2¼	3·85	0·65	4·70
Frankfort-on-Maine to Cassel ditto	70·	2¼	3·95	0·65	5·00
Ditto to Heidelberg ditto . . .	70·	2¼	3·95	0·65	5·00
Vienna to Salzburg ditto . . .	70·68	2¼	4·20	0·60	4·90
Frankfort-on-Maine to Wiesbaden do.	72·57	2¼	4·	0·70	4·93
Hanoverian State Railways . .	72·	2¾	4·	0·75	4·50
Bavarian ditto ditto	73·98	2½	3·95	0·75	4·55
Prussian ditto ditto	74·75	2⅓	4·	0·55	5·15
Baden ditto ditto	75·93	2⅔	4·40	0·80	4·70
Semmering ditto ditto	76·66	2¼	4·54	0·90	4·54

The almost universal system of supports is that of cross-sleepers. They are generally of oak, when it can be procured at a reasonable price. Different descriptions of larch and fir are often used, after being prepared by some chemical process to resist the tendency to decay. Various are the means adopted for this purpose, but the one which is now most favourably received is that of forcing a solution of sulphate of copper through the pores of the timber to be prepared. The most simple arrangement for carrying out this method is a tank erected on a wooden frame about 30 feet high, into which the solution is pumped from the tub in which it is mixed below. From the tank a main distributing-pipe descends, until reaching within a couple of feet of the ground, when it diverges into two horizontal branches, with a series of small feeders about every 3 feet at right angles to the mains, and 10 inches or 12 inches long. On these are tied flexible gutta-percha tubes 6 feet in length, furnished at the ends with brass nozzles, and having screw clamps attached to them, by which the supply can be cut off from each separate feeder, without interfering with the others. The timber to be prepared must be round, with the bark on, generally in lengths of, say, two sleepers. It is laid horizontally, on a rough supporting frame, and sawed across the middle, through about nine-tenths of its thickness. A wedge is then carefully driven under the middle of the stem to raise it up from the frame. This opens the saw-cut above, and admits of its being caulked round the outside edge with oakum. The wedge is next removed, and the cut closes up to a certain extent on the caulking, leaving a vacant space inside between its two faces. Into this a slanting hole is bored from above, and the nose of the flexible tube inserted. The clamping-screw is then loosened, and the solution allowed to flow into the centre of the tree, and acting by the hydraulic pressure from the high-level tank, it makes its way through the pores, forcing the sap out before it. When the wood has become thoroughly saturated, it is ascertained by applying litmus paper to the end of the stem. The clamping-screw is then made fast and the piece of timber removed, to make way for another. The most advantageous number of stems to prepare at the same time with one apparatus is about fifty, a similar number being always ready to supply vacancies as they occur. For success with this method, it is necessary that the timber should be cut down when the sap is in it, and prepared while green, as otherwise it occupies too much time. Also, that the bark should be whole, to prevent leakage, and that the stems should be in duplicate lengths, so as to admit of their being prepared from the centre. The average time of preparing a log 18 feet or 20 feet long, under favourable circumstances, is about twenty-four hours.

Square stone blocks are used to a considerable extent, as supports for the rails, on the Taunus Railway, but this is only on the old permanent way, as they are not made use of on the new line of rails now being laid down by this Company.

In noticing ballast on German railways, there is a system frequently to be met with which can scarcely be passed over without comment: that is, the filling up of the space outside the ballast to the level of the top of the sleepers with common earth, drains being cut through it at intervals, from the ballast to the outside slope, and filled up with broken stone. These drains, although at first answering tolerably well the purposes for which they are intended, after awhile become choked with the mud which is washed into them by heavy rains, and the free escape of water from the ballast is prevented. Add to this the mixing of the earth with the ballast, which is almost inevitable during repairs, and it becomes evident that the system has great drawbacks.

The stations on German railways are, as a rule, large and commodious, and in many cases display much architectural taste. They are generally close together.

The frequent absence of any description of fencing is also a marked feature on many German railways, the necessity for such a protection being done away with, inasmuch as cattle, except in some districts, are never allowed to stray at large without being attended by a herdsman. This latter arrangement is rendered imperative by the minute subdivision of land, which prevents the practicability of enclosing each separate property.

The quantity and description of rolling stock in use on different railways in northern and southern Germany varies greatly. The passenger carriages have principally six wheels, but there are many lines on which four-wheeled vehicles are adopted. On the Würtemberg State Railways, the long eight-wheeled carriages on the American system are in use. As nearly as can be estimated, the quantity of rolling stock at the close of the year 1861 stood thus:—

Locomotive Engines	per English mile	0·414
Passenger Carriages (averaging 41·81 seats each) .	„	0·807
Goods ditto (average load 6·91 tons)	„	7·040

Before any engine is permitted to be used, its boiler must be tested with hydraulic pressure to at least once and a half the maximum steam pressure which it is intended to sustain, and a similar test must be applied after the engine has run 46,109 miles, and subsequently repeated every time an additional 36,887 miles has been made, or whenever important repairs are required should this be sooner. In no case, however, must the intervals between such testings exceed three years. On all such occasions the weighting of the safety-valves is also proved.

With regard to the proper proportion of breaks to any train, the rule laid down fixes the minimum number according to the following scale:—

——	For Passenger Trains.	For Goods Trains.
For lines with a maximum gradient of 1 in 500	$\frac{1}{8}$ of the entire number of wheels to have breaks.	$\frac{1}{12}$ of the entire number of wheels to have breaks.
" " " 1 in 300	$\frac{1}{6}$ ditto.	$\frac{1}{10}$ ditto.
" " " 1 in 200	$\frac{1}{5}$ ditto.	$\frac{1}{8}$ ditto.
" " " 1 in 100	$\frac{1}{4}$ ditto.	$\frac{1}{7}$ ditto.
" " " 1 in 60	$\frac{1}{3}$ ditto.	$\frac{1}{5}$ ditto.
" " " 1 in 40	$\frac{1}{2}$ ditto.	$\frac{1}{4}$ ditto.

When the rate of gradient exceeds 1 in 300, it is ordered that the last carriage shall be supplied with breaks, and another rule in regard to the arranging of trains is, that between the engine and first passenger carriage there shall always intervene at least one carriage which does not contain passengers. It might have been well, when laying down such rules, to have gone still further, and ordered that the last carriage in every train, whether on a line with heavy or light gradients, should have breaks attached to it, and should not contain passengers. Where there are so few trains daily, and large quantities of small parcels and light goods requiring speedy transit, an arrangement of the kind might easily be carried out.

The rate of speed varies very much on different railways. For express trains it is usually from 27 miles to 35 miles an hour, exclusive of stoppages; the maximum velocity attained by trains while in motion being from 30 miles to 37 miles, and in some rare instances touching 40 miles. Ordinary passenger trains travel at the rate of from 20 miles to 25 miles, and goods trains at from 10 miles to 15 miles per hour, exclusive of stoppages. These comparatively low rates of speed, as might be expected, are most satisfactory in their results upon the wear and tear of both the permanent way and the rolling stock.

Mr. VIGNOLES said, he did not think the Paper should be designated as treating on the German system of railways, though it contained an interesting description of various railway structures, and there were a number of points which, when studied in detail, would be useful and instructive. Nothing was related, however, of which there were not good examples, long previously existing in this country, and of a character which, if examined, would, he believed, be found more interesting to the engineer. Many of the works which had been described he knew perfectly well; and while he gave due credit to the engineers of Germany for what they had done, he was obliged, in his own mind, to compare them with similar works executed here and elsewhere. The German system of construction was, in general, no more than adopting, in a greater or less degree, the plans which had been found successful in this country, with such modifications as the circumstances required; but their works would not as a rule bear comparison with similar ones in the United Kingdom. For instance, the viaducts built from the designs of Mr. J. Miller (M. Inst. C.E.), upon the Glasgow and Dumfries Railway, were still unequalled in Europe, for boldness of conception and excellence of workmanship, and instead of following the old Roman fashion, of building tier upon tier of arches, as was the practice on the continent, there was only one tier of arches, each pier being carried up to its full height without lateral support. With regard to the Dirschau and the Marienberg Bridges, it was unnecessary to analyse the principles upon which they had been designed, because even from the descriptions given by the engineers of those bridges, and from the diagrams published with respect to those works, it might easily be shown that their mathematical construction was faulty, there being a want of due proportion between the several parts. He had watched the progress of these works during their construction, and had ascertained that their cost had certainly not been less than £45 per ton. It must be understood that this was not said by way of depreciation, because he thought, considering the struggles that had taken place in Germany, the results were most creditable.

He was exceedingly diffident in speaking on this subject, for he had so much to do in Germany many years ago, at the time of the introduction of railways, that it was impossible to allude to that period without saying more of himself than was becoming. When, thirty years ago, he laid out the railway from Brunswick to the foot of the Hartz Mountains, then almost the first after the Nuremberg and Fürth line, he introduced that particular form of rail, of which the Author had properly stated that seven-eighths of those in use on German lines consisted, which was known in this country as the contractor's rail, but was still better known in America and on the continent as the Vignoles' rail: it was a system which he studied very much, before finally recommending and adopting it. It was properly called the contractor's rail, because the contractors were the first persons who had the courage to use it, in the face of authorities who would not at that period recognise it. At the same time he also strongly advocated the introduction, as many of his friends knew, of the system of fishing the joints of rails, which was first adopted in Germany.

The great principles, which he thought ought to have been insisted upon, as characterizing the German system of railways, were the simplification of the permanent way, and the perfection of their statistics. All the Companies were compelled, as in France, to give positive returns, under specific heads, of every detail of expenditure, and as these were published annually the Companies were brought into a wholesome competition, for the reduction of the working expenses to a minimum. Each Company was held up "in terrorem" to the others, so that all were interested in the reduction of their respective expenses. A recent inquiry showed, that the expenses per train mile on two-thirds of all the German railways were within a fraction of each other. But notwithstanding this, he believed it was capable of proof that the average expenses per train mile were less in the United Kingdom than in Germany. Still he thought it would be a wholesome regulation if Railway Companies in this country were compelled to give that information, in the same way as farmers were asked to contribute agricultural statistics. If those returns were furnished, it would be possible to trace every item of expenditure to its source, so that it would readily be seen where economy might be effected. It had been stated that the average cost of the German railways, one-fourth only having two lines of way, was £16,400 per mile; that would amount to about £14,000 per mile of single line. Now when the cost of land, the Parliamentary and legal expenses, and a vast number of other items which had unfortunately swelled the expenditure in this country were taken into account, he thought that the average cost of the lines in this country did not very much exceed that amount, particularly when of later date, those items of construction which did not fall upon the continental lines being of course eliminated.

The principle of railway legislation in Germany, as on the continent generally, was this:—The Government granted a concession for a railway from the town of A to the town of B, and sometimes provision was made, that it should run by way of the intermediate towns C and D, but all the details were left to be decided during the progress of the works. The evidence of individuals, in respect to the direction the line should go, was not taken, but the line being granted from point to point, the details were decided on the spot, where they could best be settled; and although it sometimes gave rise to considerable delay and annoyance, it saved vast sums of money. The same might be said as to the land. There was more trouble, perhaps, in getting land on the continent, but then it was obtained at the mere agricultural or mere town value.

There were a number of matters to be considered in making a comparison between the cost of lines in Great Britain and on the continent. As a rule, neither the engineers nor the labourers were so well paid on the continent, and there were various contingencies besides; so that he really thought —and it was a question he had studied for many years—when all these were taken into consideration, if the quantity of work done and its cost were contrasted, that the expenditure was not greater in Great Britain than it was, in the end, on the continent. And he would lay it down as a positive fact, that in no part of the world could work be done so cheaply as in the United Kingdom, whether measurement or weight of material were taken as the standard of comparison.

With respect to inclines, on the line between Nuremberg and Hof, on the route eastward to Leipsic, there were about 7 miles of 1 in 45, with curves of 400 yards radius, worked by locomotives. The last returns of the Semmering Railway in Austria showed that the working expenses exceeded the receipts; so great was the cost of working over 22 miles, with gradients of 1 in 40 and 1 in 45, and curves of 10 chains radius. The railway itself had been constructed at a cost of nearly £100,000 per mile, and he might mention that the bricks for the viaducts were brought from Vienna, so that the expense was enormous. However advantageous the line might be politically, and perhaps in other respects, to the Austrian Government, commercially the speculation was a most unprofitable one.

In mentioning the railway between Cologne and Liège, the Author had not noticed the way in which the passage had been effected between the two countries. The principal works were in Belgium between Liège and Verviers, and up to the Prussian frontier. They were constructed at an early period in the history of railways, and abounded in rapid curves, and comprised an extraordinary series of tunnels and viaducts; and altogether formed one of the most remarkable examples of engineering on the continent.

He had laid out the Würtemberg State Railways, and he knew they had been executed according to his recommendations; but most of the rolling stock was founded upon the American fashion, and he thought had not turned out satisfactorily. In determining the gauge for the railways in Würtemberg, Mr. Vignoles was called on to decide, whether the Bavarian gauge of 4 feet 8½ inches English, or the Baden gauge of nearly 6 feet, should be adopted. Though himself a warm advocate for a wider gauge, he felt compelled, under the then existing circumstances, to declare in favour of the narrow gauge. It was then too late to adopt the wider gauge; and the Baden Railways being isolated from the lines of Germany on the east, France on the west, and Switzerland on the south, were, as the Author had remarked, compelled to alter their gauge, and change the under-frames of their rolling stock.

The Taunus Railways had latterly been relaid, in consequence of the failure of the rails. These were originally double-headed, and when worn they were turned; but a few months afterwards they broke, as might have been expected, at a short distance from the point of support: and he saw hundreds of tons of those rails which had been broken, lying in stack. Since then a different kind of rail upon sleepers had been adopted.

Mr. T. E. HARRISON said, in his opinion the Paper contained much useful information, and although it was possible some of the Members might be acquainted with the railway system in Germany, yet the younger members, who had not had the same opportunities, could not fail to profit by it. It was stated that the average cost per mile of the whole of the railways in Germany amounted to £16,400. If this was contrasted with the cost of railways in England, undoubtedly it showed very favourably; but there were many causes which operated in favour of the German system, in respect of cost of construction. In the first place, they were exempt from Parliamentary expenses, which was a heavy item in this country; then, an exorbitant price was not paid for the land. Besides, the railways, when made, were not subject to the same competition as in England; and until lately,—for he believed a change had taken place in the views of Parliamentary Committees,—the whole basis on which railways seemed to be considered by those Committees was, that competition was a desirable thing. In Germany the lines, for many hundreds of miles in some districts, ran almost upon the surface,—while other portions were made through a country of the most difficult character,—yet on an average the cost per mile was low, and being without competition, he thought there could be no doubt that the railways there were destined to pay a remunerative interest to the shareholders. He observed also, that the Government had contributed aid, either directly or indirectly, to nearly two-thirds of the entire system. In England, that was a state of things with which they were totally unacquainted. True, in India the Government were contributing towards the completion of nearly the whole of the railways; but the lines in India would not be liable to the same competition as in England: because the Government being the guarantors, they would take care that competition should not exist. With regard to the Society formed in 1847, under the title of 'The Association of Government Railway Directions,' it appeared that part of its duties was to lay down rules for the government both of the railways and of those who had the management of them. Thus, the radius of the curves, and the maximum gradients admissible under particular circumstances, were prescribed; but after all these rules resolved themselves into the simple question,—what was the best gradient, or curve, which, having reference to the nature of the country, could be obtained? A rigid rule providing against a steeper gradient or sharper curve than a particular amount was simply impossible, inasmuch as what might be good in one state of things, where there was a large amount of traffic, would possibly entail expenses which would not be justifiable, in a case of a small amount of traffic. The question of statistics was referred to, and it appeared to be considered by some engineers in this country, that it would be a wholesome regulation, if Railway Companies in Great Britain were compelled to give detailed information as to the cost of working the lines, and that such statistics would lead to a reduction of expenditure. Now Mr. Harrison held, as regarded the management of railways, that there was no point which was of more importance to the Companies than having perfect statistics of working cost. Having been much engaged in the practical working of railways, he had felt the general advantage of that plan; but when it was urged that it would be desirable if Railway Companies were compelled to make those returns—he presumed to Government—he believed the results would not be such as had been anticipated. In so far as the statistics prepared by the Railway Companies themselves were concerned, they were invaluable; because not only the officers of the Company but also the Directors were enabled to see from time to time what expenses were incurred; and by weekly or fortnightly returns being laid before the Board of Directors, which was the case with the Company with which he was connected, showing in a tabular form the cost of each individual part of the system for a series of years, any excess of expenditure in any department could be at once detected. But then there was this difficulty—the cost even of one large system of railway could not be compared with another, without these details being accompanied by a great number of facts which bore upon that cost. For instance, on portions of the system he was more immediately connected with, the cost of maintenance of way was, in some cases, four times as much as it was on others. The working expenditure per mile reached nearly 80 per cent. on some portions of the line, whilst on other portions the cost did not exceed a minimum of about 40 per cent. Therefore, for the North-Eastern Railway Company to compare its expenditure with that of the London and North-Western Railway Company, for instance, would be to contrast two things which were totally dissimilar; and unless all the circumstances involved in the expenditure were taken into account, such a comparison would not only be useless, but would be calculated to mislead. He had seen statements, prepared with great ability, from figures exactly of the same data, of the results of the working of one Company as compared with another, the deductions from which were, to his own knowledge, exactly the reverse of the facts. He held that however valuable such statistics might be to the Companies themselves, the advantages were confined to their own particular system.

Allusion had been made, in the Paper, to the Semmering Railway. He had passed over that line, which was the work entirely of foreign engineers, and he would say that he knew no engineering work that would better repay the time and trouble of an inspection. It had been stated that, on the Southern State Railway of Bavaria, there was an embankment 172 feet in height, containing 3,000,000 cubic yards. The details of that embankment, as to the conditions under which it was carried out, were not furnished, but it was certain that in no part of England was there an embankment of that height. It appeared from the rules of the Association to which he had previously referred that the use of cast iron was completely ignored. Now he thought there were many cases in which cast iron was exceedingly useful for bridges; and though that material might be open to some objections, yet when employed in the form of segments, of which there were many admirable examples on railways in England, he could not agree in the conclusion which had been arrived at by the German engineers. The details had been given of a number of bridges of great spans, some exceeding 370 feet, which had been executed in Germany. He would suggest that it would be very useful if the Author would furnish some data from which an estimate could be formed of the cost of those bridges—either per ton of metal or per lineal foot; and in the case of tunnels the cost per yard; as it would be interesting to compare the cost of these large works with the cost of similar works in this country. The viaducts on the Semmering Railway were constructed with intermediate arches in their height. There were numberless examples of high viaducts throughout this kingdom—and those upon the Glasgow and Dumfries Railway had already been referred to; but in many parts of Lancashire, there were viaducts more than 100 feet in height, and he had built viaducts more than 150 feet in height, without a thought of introducing intermediate arches. Comparing the general designs of these viaducts, it appeared to him that those on the Semmering Railway contained more material than had been introduced into viaducts in England. Looking upon the Paper as a carefully prepared record of what had been done in a foreign country, entirely by foreign engineers, he regarded this communication as a valuable one; and he repeated that any one who visited those works would be amply repaid for his trouble.

Captain **Moorsom** remarked, with reference to the small cost of the German lines of railway, that it appeared they were laid down generally with the earthworks and bridges to receive double tracks eventually, but almost invariably waiting for the double track till the traffic should justify it. He thought a useful lesson might be taken in that respect in this country. He had only a few weeks ago perused a report from one of the Government Inspectors, in which it was noted as a matter of unfavourable character, that land had not been purchased sufficient to lay down a double track on a railway branch where only four trains each way were run during twenty-four hours. The fact was erroneously reported by the Inspector, but still it showed one of the impediments thrown in the way of economy in this country, as compared with the German system. He was at a loss to understand why 'The Association of Government Railway Directions' in Germany should limit the radius of curves to 3,600 feet on level ground, 2,000 feet for hilly country, and never less than 600 feet. He was prepared to say, that curves of 300 feet radius might in some instances be desirable. Not that in England such were frequently found, but he should not hesitate to adopt a curve of 300 feet radius, if necessitated by the circumstances under which he was obliged to lay out a railway, as he believed it would be possible to work round such a curve, to the satisfaction of the locomotive superintendent, at a speed of 20 miles or 30 miles an hour. Some years ago, he laid down a curve upon a radius of 7 chains, or between 400 and 500 feet, which remained to this day on one of the great lines of the kingdom. The trains were calculated to travel on that curve at 25 miles an hour; but when the line went out of his hands, the Directors issued instructions not to exceed 15 miles an hour round that curve, by which instructions of course all the calculations for 25 miles were falsified. With respect to the limitation of gradients to 1 in 200 in level districts, 1 in 100 among hills, and 1 in 40 on mountain lines, he remarked that the character of gradients must be guided by what the country would admit, as some countries seemed to be laid out for a certain class of gradient. Thus, in the West of England, the land was laid out for 1 in 60, and if 1 in 70, or 1 in 80, were attempted, serious difficulties would be encountered. In other parts the ground was suitable for gradients of 1 in 100. Therefore, as the country seemed itself to design the gradient on which the railway should be laid out, to limit these gradients by the dictum of book, or tables, appeared exceedingly undesirable.

The speed of the trains on these German lines appeared to be lower than was necessary. On the Semmering Railway the speed of the express trains was limited to 14 miles an hour in ascending, and to 16½ miles in descending, gradients of 1 in 40. He was satisfied that speed might be doubled with safety, from his experience in the working of the Lickey incline, of 1 in 37, on the Birmingham and Gloucester Railway, since the year 1839. The goods train at 9½ miles an hour might do very well, as high speeds were not required for goods, and it was expensive to have high speed for goods trains on heavy gradients. In descending such gradients, it was quite possible, with ordinary breaks, always to have the train under command, when travelling at a much higher speed; and the only limitation in descending upon heavy inclines was that which enabled the train to be held 'in hand.' When a train was obtaining the mastery, running ahead in fact, it was readily perceived, and there was a certain stage of progression which might be denominated the ultimate speed which a train attained, after the breaks had been got to a proper bearing; and this speed would not decrease, or increase, unless a greasy part of the line, or the falling of dews, intervened to give more sliding way. The late Mr. Robert Stephenson used always to complain of the cost of going up those heavy inclines; but Captain Moorsom believed, that the cost of working up the Lickey incline, at 28 miles an hour, was practically no more than going up at the rate of 15 miles. From the year 1840 to 1845 the speed on that incline was 15 miles an hour with passenger trains of seven or eight carriages, at a certain cost per train mile, which he did not remember, but it was per engine about £700 per annum. From 1845 to about 1855, a material improvement took place, as regarded the traffic, which increased so much as to require ten or twelve carriages, instead of an average of seven or eight, and heavier engines were used. The result was that, from 1845 to 1855, the trains of twelve carriages used to run up that incline at 28 miles or 30 miles an hour at no more practical cost than they ran in 1845 at the rate of 15 miles an hour. He referred to the accounts in verification of the correctness of this statement. He thought that embankments of 170 feet in height were dangerous to execute. He was laying out a line for the next session with 82 feet of cutting rather than have an embankment of 42 feet. The London clay or lias would slip at less heights than that, and he knew of no soil that could be trusted to the height of 172 feet. He had an embankment of 84 feet in the gritstone, but not higher than that. With respect to the bridge over the Rhine, at Cologne, to which allusion had been made, he thought it worthy of mention, that a member of this Institution furnished the design for which the Prussian Government gave the prize over sixty-one competitors of all nations. That design was for a lattice bridge of peculiar character, and very large spans. He was not certain whether the design had been carried out in all its details, but he was told that a lattice bridge had been constructed there. He mentioned this circumstance, as reflecting credit upon the Institution, that one of its members should carry off the prize as to Engineering Construction thus largely competed for, while the prize for Architectural Design was awarded to an Architect of Berlin. He quite agreed that the general contour of the Paper was useful, and that they were indebted to the Author for the statistics he had given.

Mr. J. Scott Russell said, it had happened that during the last fourteen years he had passed over many of the German railways, and he had been struck by several points which appeared to distinguish them from the railways of this country. In the first place it seemed to him that the Germans, almost first among the continental nations, set to work to ascertain what, in the British system, was best suited for their practice; and nothing surprised him more, than to see how rapidly anything successfully introduced into this country was, not copied there, but adapted to suit German circumstances and the peculiarities of the German mind. He had often asked himself the question, what could be the reason that the German engineers so quickly took to making railways, and he found but one cause, and that only accounted for it up to a certain point. He observed that, so far back as the year 1848, the German governments had taken to the belief, that a special education for engineers of all classes—mechanical and civil—was one of the first duties of a government. At that time, when young English engineers were picking up knowledge in the best way they could, there were regular colleges for the training of skilled workmen, and the education of civil engineers, in most of the great cities of Germany. By these means a set of thoroughly educated young men was prepared, ready to acquire practical knowledge, and to turn it to account in a short period of time. Many of these men were sent to England, to take advantage of the earlier practical experience in engineering works gained here, and they proved to be most apt pupils. One result of this was rather remarkable. Sooner, he thought, than any other country the Germans took to making locomotive engines. The English types were at first implicitly copied, but when once that was accomplished, and engines had been fairly constructed, the German engineers took to making designs for themselves, and departed more and more from the established patterns; so that now the engines on most of the principal lines were made exclusively in Germany, and in some cases at a less cost than in this country. It was still more remarkable that German engineers were now tendering against the British in many foreign markets; and it was even said, that one firm, that of Borsig, of Berlin, had recently successfully competed in England. From the manufactory he had named many beautiful and admirably constructed locomotive engines were sent out, and they were far from being copies. In another case he knew that a German house had taken a large iron bridge contract from the best English houses.

Another circumstance which attracted his notice was, as it could not fail to do that of any engineer—the character of the earthworks. Immense trouble was evidently taken, the works were executed with great nicety and skill, and the result was, there were few slips. He believed that might be partly owing to the fact, that many of the early earthworks in Germany were designed by military engineers, who bestowed more care and attention upon earthworks than railway engineers. With regard to the gradients, he quite agreed in the view already expressed, that it was pure pedantry to attempt to dictate the gradients on any class of lines. The country and the circumstances must determine what these should be. Great mistakes had been made on some German railways from the adoption of theoretical gradients for a long line of country, where, in order to preserve—say a gradient of 1 in 200—many miles of moderate cutting had been incurred, which might readily have been avoided, if the contour of the ground had been more closely followed. It was true, the curves were generally of much longer radius than in this country, but that also was due to the character of ground passed over. Germany was, in general, well suited to the construction of railways, because there were long tracts of level land; and it was easy to concentrate the gradients upon that place where any auxiliary power that might be wanted could be obtained. Great judgment had been shown in the early adoption of a cheap permanent way, including the fish-joint, which, he might remark, it was somewhat astonishing was only first used on the great lines in this country, about ten or twelve years ago, after the Germans had adopted it almost throughout their entire railway system. The waggon-stock was peculiar. It consisted of long square boxes, or warehouses, placed upon two laurries, on four wheels; and was perfectly watertight, instead of being composed of open trucks, covered with tarpaulin. It was said that the goods were carried with great care, and were delivered in admirable condition.

In the first-class carriages, seats for four passengers abreast had been all along provided. Whether that was a convenience, or not, to individual passengers was a question; but the plan was coming into use in this country. In regard to the first cost of the German railways, he did not think there was much merit in that. The country itself was not of a nature to demand expensive works; and to compare the two countries—so different as the great level cornfields of Germany to the hilly undulating garden of England—would give no useful information. It was no doubt true, that many expenses necessarily incurred here were not repeated there; but it was entirely a question of country; and he regretted that the papers had not entered more fully into details on this subject, because it would have been useful to know what the great bridges and the earthworks had cost in the two countries respectively. In regard to management and economy of working, he thought there was much to be explained. In the first place, on the German lines less accommodation was given than on the English. The trains were very heavy, but they were run seldom, and at slow speeds, comparatively, and in that respect offered little public convenience as compared with the metropolitan lines. Therefore their economy of making did not go for much. It must also be remembered that the stations were far apart, and therefore there was not the loss in stopping and in starting which was incurred on more frequented lines. Then again, in regard to the earnings of the lines, there was another element besides first cost. It was this—he did not remember to have heard it stated what the comparative fares were; but a friend of his, who had a large trade in minerals, had made inquiries in this country as to the cost of the carriage of goods, minerals, and heavy traffic, when he found that the current rates on German railways were two or three times greater than on railways in England. That was another cause why the earnings should be higher, without there being any superiority over English railways. If the accommodation was less, the speed slower, and a higher sum was charged for the transport of goods, it was plain these were elements which would cause larger dividends to be realised on comparatively smaller capital. These were a few of the main circumstances which he thought distinguished German railways, and he believed would go to show, that though German railways had great merit, yet it must not be considered that all these apparent advantages were really advantages to the country through which the railways passed, and whose interests those railways were intended to serve. The Institution was under great obligations to the Author of the Paper, and the young engineers of England could not do better, than ascertain what their professional brethren were doing in other countries; for, as far as he was able to judge, although English engineers were at present superior to the engineers of all the countries of Europe, he had the impression that the engineers of other countries, especially on the continent, were making more rapid progress.

Mr. **Mallet** said, he had had a good deal of experience, while a mechanical engineer and contractor, of the methods employed in this country and abroad in the construction of railways. Last year he had travelled over many German railways, and upon some lines not commonly visited by Englishmen. For his part he felt unbounded admiration of German engineers, and he was satisfied that, as regarded sound technical education, the comparison between the English engineer and the German was much in favour of the latter, and increasingly so. Such an expression of opinion would probably be unpopular, but if true, it was nevertheless wholesome to be heard. As an illustration of the general truth of the opinion, as to the imperfect character of engineering education in England, he would ask any one who had visited the Western Annexe of the International Exhibition of 1862, which amongst the steam engines there shown displayed most mind and knowledge of principle, and the best advance towards theoretic perfection. Not certainly any of the English ones, but two of American origin, one improved and carried out by Germans. With respect to originality of construction manifested in the German railways, no doubt the earliest lines in that country were suggested by the successful creation of the railway system in England. They were, he believed, not designed by military engineers, but by officers from the Bergampt (School of Mines), the first ideas of railways being taken from those of their great projector, George Stephenson; but the works were carried out in their own way from the commencement, and with striking originality in structural detail. So far from having copied English engineers, the latter had in several respects copied them. The lattice bridge in iron was in fact introduced from Germany. One of the earliest German.iron lattice bridges was that across the Elbe at Magdeburg, the wooden lattice having been long previously known and adopted in America. Sir John Macneill, who was the first to employ iron lattice bridges in this country, took his earliest examples, in Ireland, from this and other early German bridges. Mr. Mallet would venture to say that he believed, in the end, the lattice bridge, in iron, in one form or another, would supersede all others for railway uses.

He had recently been over a new line of German railway, the Deutz and Giessen, which ran along the valleys of the Lahn and Sieg, through, in great part, a very uneven country, one very unlike the level plain of Central Germany, so commonly supposed to form the basis of all German lines. This line comprised a vast amount of heavy earthworks, and over bridges, and extensive lattice viaducts repeatedly crossing the Lahn, a large navigable river, and it passed through a country more difficult than any he had seen in England. In one place, for 14 miles in length in one stretch, the gradient was 1 in 40, and nowhere less than 1 in 80; almost all this was in rock cutting and side embankment, and the line was obliged to take curves in the form, in some places, of the letter U. That line, he understood, had been made nevertheless at an expense of about £12,000 per mile. The bridges over the Lahn were on the lattice principle, and were beautiful examples of structural skill, and in some points novel. One characteristic of the German railways was well worthy of imitation; that was the care taken to prevent accidents, which seemed to be to a great extent neglected in this country. Some years ago a brother of their member Mr. Siemens, himself a German engineer by education, proposed a mode of telegraphing along all the lines, by which each train, as it started, telegraphed its approach to the station immediately in advance. That system was adopted on every line, he believed, and the result was an almost entire immunity from accidents on German lines. It was not correct to suppose, that the freedom from accidents on the German lines arose from their running few trains, or that these invariably travelled at a slow rate. In Westphalia, the grand centre of German industry, on the trunk lines, as many trains ran as on some of the English lines, and the speed of the express trains was 40 miles an hour, while the average speed of ordinary trains was 4 German, or nearly 21 English miles per hour. Repeated efforts had been made to get the same system introduced here, but the attempt had been nugatory except in one or two instances. This inertness to improve in England might be illustrated by a smaller matter. Nearly all the railways in Germany had their axles lubricated with liquid oil, instead of solid grease, the imperfect material in universal use here; one loth, or ounce of oil, serving to grease an ordinary axle for a month. About fifteen years ago, he introduced a mode of oiling the axles of railway wheels which, although independently invented by him, turned out afterwards to be identical with that in use in Germany on certain lines. He endeavoured to get the method tried on some English lines, but was met by the statement, that however good it might be, grease was so generally employed that no change would be made.[1] In Germany there was an admirable system at work for the technical education of engineers and others engaged in skilled and scientific employments with which there was nothing to compare in this country, and it would be well to study it and to adopt it as far as possible, otherwise this nation would, in this respect, assuredly fall into the rear.

In illustration of the rapid expansion of German industry, Mr. Mallet then directed attention to a map, annually produced by the 'Oberbergampt,' which exhibited, graphically, the progress and distribution, year by year, of the coal industry of Prussia. It showed the tons of coal raised, used and exported, from each of the great coal basins—the Westphalian, the Saarbrücken, the Silesian, &c.—and also the imports and distribution in Germany of coal from England. This was at once an indication of the perfect way in which Germany treated every question, and an illustration of the enormous progress of German industry and railway traffic. The Westphalian basin alone contained more coal than the whole of Great Britain. A comparison of that map, over a few consecutive years, would show, how steadily British coal exports were decreasing all over the continent, and the product of German coal increasing. Germany had now got an abundance of coal, and everything needful for industrial success along with it. It was in itself the source to her of direct wealth, and the creator of every other form of riches. If then technical education in this country was not made to keep pace with that of Germany, the British would not long maintain that relative manufacturing pre-eminence which they had hitherto held amongst the nations of the earth. He regarded the growing prominence of Germany in the industrial arts as mainly owing to the more perfect education of all its technical classes. The great movement in education dated in Prussia from the year 1813, when Germany shook off the despotism of Napoleon. Education, in its primary rudiments, was compulsory on all; so that no one could stand between the child of Prussia, and that fundamental knowledge that should fit it, in whatsoever station, to become an honour, and not a disgrace, to the fatherland. Moreover, the gymnasia, and the universities were better fitted for technical education than in Great Britain, where, as an organized system, there did not exist, between the elementary schools (more particularly for the middle and wage classes) and the universities, any efficient system of technical education at all. There was thus a great gap, filled only by a few isolated institutions, such as the Museum of Practical Geology, &c. The superiority in result of the German system was not badly indicated, by comparing the 'Taschenbucher,' or pocket-books of data, in use in that country, with those found here. The German books were prepared by men of thorough and exact information, and were obviously addressed to persons who had already received the fundamentals of a sound general education, and hence were prepared to accept and apply scientific and technical data in an exact and technical form. Similar books in this country were addressed to men, who were yet supposed not to have the elementary knowledge of well-educated schoolboys; and as such books were in demand, it was plain that English artisans, &c., really had not on the whole that amount of preliminary knowledge.

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[1] An attempt is now (September, 1865) being made to try oil as a lubricant on some passenger carriages on the London and North Western Railway.—R. M.

Mr. SHEILDS said, that in the north and north-east of Germany, everything in the way of railway works was so plain and simple, and so like what it was in any easy district of country at home, that there was not much to remark upon. The expenditure upon the railways had been small from a variety of reasons, one being that the population supplied an excellent industrious class of workmen, and the work did not appear to be hurried so much as was the case in this country. There was a less amount of work to be done, and being carried out more slowly, large bodies of workmen were not collected together, by which the price of labour was raised to an artificial height. The German navvy was paid about 1*s.* 6*d.* per day, and did a large amount of work, so that he believed throughout Prussia the cost of the earthwork did not exceed 8*d.* or 9*d.* per cubic yard. It was to be remarked, that but little contractors' plant was employed, the embankments being executed mostly from side cuttings, with barrow runs of much greater lengths than in this country, even up to 300 yards. This might account, in a great degree, for the excellence of the earthwork to which allusion had been made. The stations in Germany had been spoken of as being excellent; and he was surprised that the Author had not noticed especially the station at Breslau, which was perhaps one of the finest in Europe, as regarded architectural effect. In his opinion, the German lattice bridges should not be taken as models of the best design and construction. The lattices were composed of flat bars, which were inherently weak in themselves, and which, however they might be supported at intervals, by vertical bracings, to keep the top and bottom flanges apart, were imperfect constructions. It was, he thought, far better to give the lattice bars the necessary rigidity in themselves, than to make them inherently weak, and supply what was deficient in them by additional construction. He had made such girders some years ago, when it was the customary practice, but he found their deflection to be very great; in consequence, he had since adopted the system of employing angle irons for the lattice braces, whether in tension or compression, or of using plate girders, which undoubtedly formed a good strong bridge. The rolling stock was of excellent construction, and the passenger carriages most commodious; but the trains were few in number, and in most cases several hours apart. Under such circumstances, he did not think that so much credit as had been claimed for them was due for their freedom from accidents. In fact, no fair comparison could be made in this respect between the German and the English systems; and he believed that if the trains ran as frequently on German lines as on those in England, it would be found that as great, if not a greater number of accidents would take place on the former than on the latter.

Mr. **Cockburn Curtis** said, notwithstanding the remarks which had been made, he did not feel any apprehension, that English engineers would be surpassed in professional ability, or practical attainments by their German, or other continental brethren. Such a result certainly would not be owing to any fault in their present mode of education; but if it ever unhappily did take place, he considered it would be more likely to be occasioned by the substitution of a theoretical system of training, for the practical apprenticeship, and the test of public confidence, in existing works, which had hitherto been the credentials of the English engineer. It must be remembered, that the qualifications required in an efficient engineer were more of a practical than of a theoretical character, and that the great object in educating a youth for the profession was to strengthen his thinking and working powers, by habits of self-reliance and by the acquisition of such an amount of scientific and practical knowledge as would be readily available in cases of emergency. He contended that no amount of theoretical knowledge, however easily it might be insinuated into the mind by treatises and compendiums, could compensate for the ready aptitude, and difficulty-overcoming power, which was attained by that continuous labour which simultaneously connected scientific knowledge with actual experience. Mr. Curtis had never been in Germany, but his personal experience in other continental countries, where similar institutions and systems had been adopted for the education of engineers, induced him to believe, that any advance that might have been made in the efficiency of the German engineers was rather to be attributed to the national development of a healthful spirit of speculation and enterprise, and the consequent necessity which had arisen for emerging from the previous state of crude and pedantic theory, of which instances had been given and commented upon in the course of the discussion; and upon the whole he considered that while the evils of the English system of engineering education were probably overrated, on the other hand, it would be impossible to overrate the evils that might arise from transplanting the German, or any other continental system of educating engineers into this country.

Mr. C. H. **Gregory** said, he was afraid the effect of some of the observations which had been made might be of a depressing character, as regarded the capabilities and prospects of English engineers. He observed, however, that the map which Mr. Mallet had alluded to showed, that notwithstanding the great advantages arising from the Prussians having coal-mines close at hand, still English coal found its way into that market, and competed with the coal of the country, in spite of the expenses of transport. With regard to the alleged advantages of special education, without venturing to depreciate that which was a valuable aid to the labour of all classes, and very useful in assisting the engineer, and the practical man, to the best way of attaining his object, yet he submitted that undue importance should not be attached to theoretical education, to the neglect of that practical experience and training which the engineer should always bring to bear upon his profession. The history of engineering in this country showed that the works which reflected the highest honour upon the profession had been carried out, to a great extent, by men who had not any large amount of special theoretical education, but who, being possessed of great natural powers, were enabled to take advantage of the national resources and peculiarities in such a way as to command for English engineers universal respect. He thought that this result would not have been attained, if they had relied upon a technical theoretical education, and systematized rules, cut and dried by others, instead of their own energy and originality of mind and action.

Mr. MALLET was far from wishing to disparage the achievements of those who had been the great fathers of English engineering; but he would ask, how much greater would those achievements have been if these undoubtedly great men, the Brindleys and the Stephensons of engineering history, in place of having to employ their grand intellects in hammering out imperfectly, and as best they could, the information they needed, had had that educational training that would have placed at their command, in orderly array, the accumulated stores of knowledge of all mankind in all time past, and the power that such confers?

Mr. CRAWFORD observed, through the Secretary, in reference to a remark that the works between Verviers and Liège, on the line from Cologne to the Prussian frontier, had not been described in the Paper, that that railway was in Belgium, and being beyond the Prussian frontier, was not within the limits treated of in the Paper. The principal works of interest on the railway from Cologne to the Prussian frontier, namely, the incline at Aix-la-Chapelle and the large tunnel, one of the first constructed in Germany, were alluded to.

November 18, 1862.

JOHN FOWLER, Vice-President,
in the Chair.

THE Discussion upon the Paper No. 1,071, on "The Railway System of Germany," by Mr. R. CRAWFORD, was continued throughout the evening to the exclusion of any other subject.

November 25, 1862.

JOHN ROBINSON M'CLEAN, Vice-President,
in the Chair.

No. 1,058.—"The Hownes Gill Viaduct, on the Stockton and Darlington Railway." By WILLIAM CUDWORTH, M. Inst. C.E.

THE Stockton and Darlington Railway has been no exception to the system of gradual extension, which appears to be so commonly the policy, or the necessity of railway management. Its length, at the time of its opening in 1825, was 25 miles. It has now spread out, by numerous ramifications, to 183 miles. The branch upon which the Hownes Gill Viaduct has been erected was formerly the western part of the Stanhope and Tyne Railway. After the dissolution of that Company the part referred to came into the hands of the Stockton and Darlington Railway Company, in the year 1844. On account of the mountainous character of the country traversed by this branch, which has a summit level of about 1,450 feet above the sea, the adoption of steep gradients, worked by stationary engines and ropes, though diversified with occasional intermediate lengths comparatively level, was unavoidable; but it was carried to a greater extent than would be consonant with modern ideas. Thus, Hownes Gill, a dry ravine 800 feet wide and 160 feet in depth, situated near the Consett Ironworks of the Derwent Iron Company, in the north-western part of the county of Durham, was crossed by a descent and ascent corresponding with the contour of the Gill; the gradient on the west side being 1 in 2½, and that on the east side 1 in 3. A small traffic, conveyed in chaldron waggons, was for some years taken over these gradients with little difficulty, although encumbered with what subsequently proved to be a needless contrivance, for preserving the waggons in a horizontal position. This consisted of cradles, or carriages, one for each incline, having front and hind wheels of unequal diameter, upon which the waggons travelled side foremost. Only one waggon could be passed across in each run, and delay and expense were incurred, by each having during its transit to be turned upon four turntables. It was, however, arranged that both inclines should be in operation at once, by which means the gravitation of the descending waggon aided the engine in drawing up the ascending one.

Soon after the connection of this branch with the Stockton and

Darlington Railway, the increased traffic was objectionably retarded at the Gill, and greater facility of transit became imperative. This was obtained by the simple removal of the cradles and turntables, and by allowing the waggons to travel upon their own wheels, when three could be linked together in a train, and passed across in less time than was previously occupied by one. This alteration was satisfactory, and the Gill was worked well for a time; but a large accession of traffic, consequent upon the discovery of the Cleveland ironstone, and its purchase by the Derwent Iron Company, at length demanded further accommodation. The trains were necessarily limited to three waggons, to avoid putting undue strain upon the couplings, and various methods of obviating this restriction were considered; but nothing less than the erection of a high level viaduct seemed to offer a satisfactory solution. The idea of a viaduct had been a favourite one with the Directors of the Stockton and Darlington Railway Company from the first; but for some years the traffic was insufficient to warrant the necessary outlay. As early as the year 1844, with the view of ascertaining the probable cost, the Directors issued advertisements offering premiums for the two best designs of viaducts, to be accompanied with estimates of cost. This met with a ready response, but the estimates attached to the premium drawings exceeded £17,000. When, in 1853, the subject became more pressing, the remembrance of the premium experiment was sufficiently encouraging to induce the Directors to repeat it. Upon this occasion their attention, and that of their engineer-in-chief, Mr. John Dixon (M. Inst. C.E.), was attracted by a design sent in by Mr. John Anderson, then of Edinburgh, now of Middlesbro'-on-Tees, contractor, and prepared by Mr. Thomas Bouch (M. Inst. C.E.), as it was accompanied by a tender to erect the viaduct, and to uphold it for twelve months after completion, for the sum of £11,697 if built of common brick, or of £13,237 if built of firebrick. The design represented twelve arches each of 50 feet span. Although the ability of Mr. Anderson was well known to the Directors, and although they had also great confidence in Mr. Bouch, it was thought desirable to consult the late Mr. Robert Stephenson, M.P., as to the sufficiency of the design. In the interview which Mr. Dixon had with Mr. Stephenson, when Mr. G. P. Bidder (Past-President Inst. C.E.) was present and gave his advice, a general approval of the plan was expressed, with some limitations and recommendations, as the proportions of the viaduct were considered to be such as to leave no margin for inferior material, or workmanship.

Nearly three years elapsed before further action took place. At length, in 1856, Mr. Anderson's offer was accepted, to erect the viaduct in fire-brick, set in hydraulic mortar, the arches to be in cement, for the sum of £14,100. As the premium drawing, with the modifications suggested by Mr. Stephenson and Mr. Bidder, was the basis of this contract, the sum required to be readjusted, when the circumstances of the foundation, site, &c., had been considered. In December, 1856, a revised contract was entered into, referring to a duly matured working drawing and specification. Mr. Anderson then undertook to erect the viaduct in eighteen months, and to uphold it for twelve months after completion, for the sum of £14,614. To avoid interfering with the traffic over the inclined planes, a deviation of the line was an obvious necessity. The piers in the slopes of the Gill found a firm foundation on the shales and stone of the coal measures. The only difficulty was the occurrence of abandoned iron-stone drifts, the entrances to which were concealed by a thick cover of débris. A careful probing of the doubtful foundations, with boring-rods, was therefore resorted to. Some of the drifts were entered and explored, and eventually both the abutments were sunk through the strata in which the mines occurred. In the bottom of the Gill there was a thick bed of heterogeneous material, consisting of the débris of the slopes, into which a bore-hole was put down for 30 feet, without indicating a change of stratum. Although this bed was by no means of a soft nature, it was not deemed firm enough to sustain the great weight of the structure with ordinary foundations. At the suggestion of Mr. Stephenson, the bases of the three central piers were extended, by the application of inverts, until the weight scarcely exceeded 1 ton per superficial foot. The choice of fire-brick, in preference to common brick, was made with the view of having the best material, the common bricks of the neighbourhood being inferior both in strength and regularity of shape. Large quantities of fire-bricks are made at the collieries in the district, for the linings of the coke ovens and of the iron furnaces of Cleveland.

The extreme length of the viaduct (Plate 1) is 730 feet, and its greatest height, from the bottom of the inverts to the level of the railway, is 162 feet, or from the surface of the ground about 150 feet. There are twelve semicircular brick arches, each 50 feet span, 14 feet in length, and 2 feet 6 inches in thickness, set in Portland cement. The inverted arches in the foundations, four in number, have a versed sine of about 14 feet, and are 38 feet in length, and 3 feet in thickness. The brickwork in these, as well as in the piers, and in the whole of the viaduct, with the exception of the arches, was set in hydraulic mortar. The height of the five loftiest piers, measured from the springing of the inverts to the springing of the arches, ranges from 114 feet to 110 feet; that of the six remaining piers diminishes rapidly towards each end. Their length is 14 feet at the top, and 38 feet at the bottom, in the case of the high ones, the latter dimension corresponding with that of the inverts. The piers down to within about 15 feet of the inverts are stayed with buttresses, which are transverse to the line of the viaduct. At this point they are only 17 feet 6 inches in length, but below this level the buttresses merge into the piers, when they together present a rectangular horizontal section 38 feet in length. The buttresses are 3 feet thick at the top and 5 feet thick at the bottom; their projection from the piers being increased by offsets at intervals of about 35 feet. The piers, although light in their proportions, are reduced by recesses 7 feet 3 inches wide, and averaging 3 feet 9 inches deep, in each side, so that the horizontal section of the pier and buttresses is in the form of a double cross, the brickwork left in the middle being only 2 feet thick. These recesses are not continuous throughout the pier, but are divided into three compartments, the solid parts between affording facility for the introduction of two bond courses of stone, the continuation of which through the buttresses forms a finish and protection to the offsets. The amount of brickwork abstracted from one pier by the adoption of the recesses is 142 cubic yards, or about 14½ per cent. of the contents of a solid pier without recesses.

Between the spandril walls, which are of brick 3 feet thick, two internal parallel walls of stone 2 feet thick were introduced, to sustain a platform of flagging 6 inches thick, upon which the 'way-beams' and ballast are carried. The arches between these walls are kept dry by a layer of puddled clay, which conveys the water to discharging-pipes over the piers in the usual manner. The way-beams are of Memel fir, 12 inches by 12 inches. They were at first fixed to the flagging with bolts secured to the internal walls; but it was soon found that there was an objectionable rigidity in the permanent way, indicated by the working of the ballast and the occasional fracture of a joint chair, and accompanied by an unpleasant amount of vibration. These evils were remedied by simply removing the nuts from the locking-down bolts, lifting the way-beams 6 inches, and interposing that thickness of the common coke ballast of the district, between the way-beams and the flagging. The external walls were covered with a simple projecting string course, 3 feet 6 inches by 1 foot 9 inches, and upon this was fixed a substantial cast-iron railing, forming the parapet. The choice of iron was more than a mere question of taste, it effected a considerable saving of brickwork; for if a brick or a stone parapet had been adopted, the upper part of the viaduct, including the arches, must have been about 16 feet wide, instead of 14 feet.

The fire-bricks, which were of excellent quality, were obtained chiefly from Pease's West Fire-brick Works, near Crook, about 14 miles from the viaduct, but having railway communication with it. They were 9¾ inches by 4¾ inches by 3 inches in size, weighed 9 lbs. 11 oz. each, and cost the contractor 26*s.* 6*d.* per thousand at the works, which the railway dues increased to 31*s.* 2*d.* per thousand at the viaduct. The number used was 2,655,000. The greatest care was taken to insure the adhesion of the mortar and the solidity of the work, the bricks being freed from dust, well wetted, and set with a mallet. The internal work was as good and solid as the external portion; and in the arches, which were constructed in half-brick rings, whenever the coincidence of two courses admitted of it, radiating bond bricks, moulded for the purpose, were introduced. It is gratifying to be able to state, that not a single crack can be discovered in the whole of the structure.

The scaffolding used in the erection of the viaduct was of a very light character (Plate I.). It proved, however, to be sufficiently strong, and the work was completed without accident. The erection of the scaffolding was considerably facilitated by the hoisting tackle being made to traverse a stout wire rope stretched across the Gill, and firmly fixed at each side to the roots of trees. When the arches were about to be turned, the piers were stayed with two parallel wire ropes, 1¼ inch in diameter, stretched from end to end of the viaduct, and firmly fixed to the abutments and large springing stones of the arches. The first brick was laid on the 24th of February, 1857, and the first train passed over the viaduct on the 1st of July, 1858. The cost of the structure, which was increased by the additional depth of the foundations, a much heavier parapet than was originally specified, and other contingencies, amounted to £15,756. This may be analysed as follows, the prices affixed being those given in the contractor's schedule:—

				£.	*s.*	*d.*
Excavation	7,254	cubic yards, at	1*s.* 9*d.* .	634	14	6
Brickwork in inverts . . .	999	„	20*s.* .	999	0	0
Brickwork in piers, spandrils, &c. .	6,796	„	19*s.* .	6,456	4	0
Brickwork in arches, set in cement.	1,371	„	22*s.* .	1,508	2	0
Ashlar masonry in foundations .	4,558	cubic feet, at	1*s.* 6*d.* .	341	17	0
Ashlar masonry in piers . .	30,977	„	1*s.* 9*d.* .	2,710	9	9
Broken stone in foundation of west abutment	96	cubic yards, at	5*s.* .	24	0	0
Rubble masonry in backing of arches and internal longitudinal walls .	1,083	„	9*s.* 6*d.* .	514	8	6
Flagging, 6 inches thick . .	795	square yards, at	6*s.* .	238	10	0
Cast-iron parapet railing				688	10	9
Scaffolding, centres, and contractor's contingencies . . .				1,581	0	4
Examining foundations, draining, etc				59	3	2
			Total . . .	£15,756	0	0

Regarding the viaduct as an unpierced solid, its contents would amount to 61,910 cubic yards, and its cost would be 5*s.* 1*d.* per cubic yard.

The question of the relative cost of brick and iron viaducts having engaged the attention of the Author, he will proceed to state the result of his inquiry. In his capacity of Engineer to the Stockton and Darlington Railway Company, he has under his care, besides the Hownes Gill brick structure, two iron viaducts, recently erected by Mr. Bouch, on the South Durham and Lancashire Union Railway.

These iron viaducts consist of three lines of trellis girders, resting upon skeleton piers, each of which consists of six cast-iron columns 12 inches in diameter, jointed at intervals of 15 feet, and braced together by horizontal cast-iron struts, and by vertical and horizontal diagonal tie-bars of wrought iron. The clear spans between the piers are in all cases 48 feet.[1]

The Beelah viaduct is 1,000 feet in length and 197 feet in extreme height. The Deepdale viaduct is not so large, and more nearly resembles the Hownes Gill in its proportions, being 740 feet in length, and about 160 feet in extreme height. If applied to the Hownes Gill valley, it would only need the removal of one tier of columns in three of the piers to adapt it to that site. The cost of the Deepdale viaduct being £20,266, and that of the Hownes Gill viaduct £15,756, the first impression would be in favour of the brick structure. But further investigation would considerably modify this conclusion. The brick viaduct has only width for a single line of railway; the iron one was constructed to carry two lines. Considerable expense has been incurred upon the foundations of both structures, but in dissimilar ways; and it would be mere hasty assumption to treat the outlay upon one as a fair offset to that upon the other. It was thought that the best way of making a comparison would be by calculating, from the data already obtained, what would be the cost of the Hownes Gill viaduct if it were widened 11 feet, so as to carry a double line of railway, and then by computing what would be the cost of an iron structure, like the Deepdale, if erected across Hownes Gill, omitting the inverts in the former case, and adjusting the spread of the bases of both viaducts, so as to sustain a weight of 2½ tons per superficial foot, including the greatest moving load. The prices of the brickwork and of the masonry in both erections were taken from Mr. Anderson's schedule; those of the timber and ironwork were the prices actually paid to Messrs. Gilkes, Wilson, and Co., of Middlesbro', the contractors for the South Durham and Lancashire viaducts, minus a deduction of 10*s.* per ton, the cost of cartage over country roads, which was not incurred upon the material for Hownes Gill. With this adjustment, the price of the cast-iron work was £9 2*s.* 6*d.* per ton, that of the wrought-iron work £22 7*s.* 6*d.* per ton, and that of the timber 2*s.* 0½*d.* per cubic foot, including erection and 32 miles of railway carriage. It was found that the cost of the viaducts calculated in this way, the details of which are given in the Appendix, would be £20,681 for the brick structure, and £16,249 for the iron one, giving a difference of £4,432 in favour of the latter. It is probable, however, that the interest on this sum, say £222 per annum, would be absorbed in the periodical examination and painting of the iron structure, and the depreciation of its perishable timber platform; and it may be assumed, that at the place referred to, a brick viaduct would be, ultimately at least, as cheap as an iron one. If the comparison were made between viaducts designed to carry a single line of railway, it is believed that the balance would be more evidently in favour of a brick one. Although the Author strongly prefers brick or stone, he by no means regards iron viaducts as ineligible under all circumstances. The Beelah and the Deepdale viaducts have stood remarkably well, no loosening of the bolts or cotters from vibration having been observed, while their steadiness during the passage of the trains is such as to inspire confidence. Much of this firmness is to be attributed to the excellent workmanship and the perfect fitting of the parts, for which great credit is due to the enterprising contractors.

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[1] A description of these viaducts, with drawings, is published in Mr. Humber's work on "Iron Bridge Construction." 2 vols. 4to. London, 1861.

The material to be used in the construction of any viaduct must depend upon local and other considerations, among which the absence of expensive carriage, and the facility afforded for expeditious erection, are not the least important. In situations which do not yield suitable building materials, and where there are no cheap means of conveyance, as by railway or by water, from a distance, the small relative mass of an iron viaduct would be a strong argument in its favour; for the whole weight of such a structure, including its foundations of masonry, would be less than one-fifth of that of a brick one. This might also lead to the selection of iron in cases of doubtful foundations. If, in the viaducts which have been compared, the material of every description had to be conveyed 20 miles at a cost of say 9*d.* per ton per mile, there would be an increase of cost of £17,719 or 85 per cent., entailed upon the brick structure, but of only £3,464, or 21 per cent., upon the iron one. The possible absence of scaffolding is also worth something, for the Deepdale and the Beelah viaducts were erected in a masterly way without its aid, and with such expedition in the case of the latter, that after the masonry foundations were laid, the fifteen iron piers with their girders were erected in less than five months. The South Durham and Lancashire Railway passes through a mountainous country, where stone is the only building material. Structures in masonry are notoriously slow of execution, and there is no doubt, that if this kind of work had been adopted in the Deepdale and the Beelah viaducts, the completion of the line would have been retarded two or three years. It was important, too, that the Deepdale viaduct should be completed long before the opening of the line, as nearly 200,000 cubic yards of earth had to be removed from a cutting to form an embankment on the opposite side of the valley. Under these circumstances it is submitted that Mr. Bouch exercised sound judgment in selecting iron as the material for these viaducts.

The Paper is accompanied by two drawings from which Plate 1 has been compiled.

APPENDIX.

ESTIMATE of the COST of a BRICK VIADUCT, for TWO LINES of WAY over HOWNES GILL, without INVERTS.

			£	s.	d.	£	s.	d
Excavation	10,068 cubic yards	at	0	1	9	880	19	0
Brickwork in piers	9,730 „	„	0	19	0	9,243	10	0
Ditto in arches	2,388 „	„	1	2	0	2,626	16	0
Ashlar in footings	18,366 cubic feet	„	0	1	6	1,375	4	0
Ditto in piers	36,052 „	„	0	1	9	3,154	11	0
Rubble in internal longitudinal walls, &c.	1,971 cubic yards	„	0	9	6	936	4	6
Flagging to carry roadway .	1,615 square yards	„	0	6	0	484	10	0
Iron railing	477½ yards	„	1	8	10	688	17	11
Bolts	1,730 lbs.	„	0	0	4½	32	8	9
Scaffolding			..			1,200	0	0
Draining foundations, &c.			..			58	0	0
						£20,681	1	2

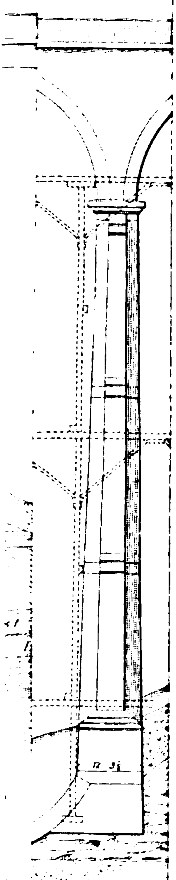
ESTIMATE of the COST of an IRON VIADUCT over HOWNES GILL, similar in design to that at DEEPDALE.

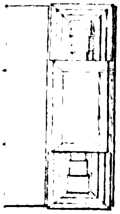
			£	s.	d.	£	s.	d.
Excavation	6,160 cubic yards	at	0	1	9	539	0	0
Ashlar in footings	21,523 cubic feet	„	0	1	6	1,614	4	6
Ditto in string course of abutments, &c.	1,186 „	„	0	1	9	103	15	6
Rubble in retaining walls to protect metal columns . .	199 cubic yards	„	0	9	6	94	10	6
Brickwork in abutments . .	1,317 „	„	0	19	0	1,251	2	0
Cast iron	603·1 tons	„	9	2	6	5,503	5	9
Wrought iron	275·75 „	„	22	7	6	6,169	18	1
Brass slides and moveable bearings.	2cwt. 2qr. 12lbs.	„	0	2	0	29	4	0
Wrought-iron stays, bolts and nuts for handrailing . .			..			17	9	1
Timber in transverse beams and planking	8,891 cubic feet	„	0	2	1	926	2	11
						£16,248	12	4

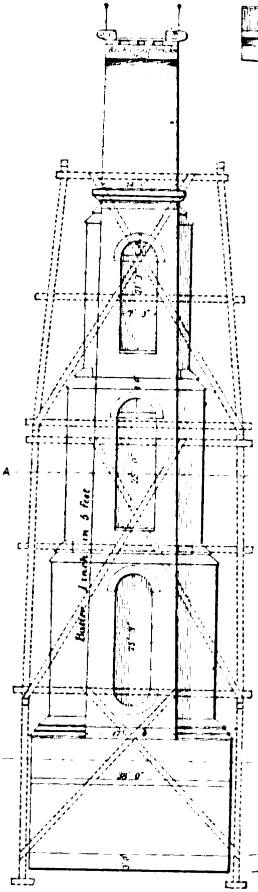
Mr. **Cudworth** said, he had but little to add to the Paper, in which, although condensed as much as possible, it did not occur to him that anything material had been omitted. He was glad to have had the opportunity of bringing under the notice of the Institution, a viaduct in which economy of materials had been much studied, and in which this appeared to him to have been carried almost as far as was consistent with due regard to safety. He had brought into comparison with this viaduct one constructed of iron; and as both structures were designed by the same Engineer, it might be inferred that similar ideas, as to economy of materials and of fitness, prevailed in both cases.

Mr. G. P. **Bidder**, Past-President, said, every Engineer must be guided in the selection of the particular material, or mode of construction, by the locality, the facility of obtaining different materials, and the purposes which the work was intended to serve. No doubt viaducts, like all other works, were now constructed at less cost than was the case in the early days of railways, when the stereotyped price of a viaduct was 6*s.* 8*d.* per cubic yard. It appeared from the Paper, that the Hownes Gill Viaduct had cost 5*s.* 1*d.* per cubic yard. This was a reduction of nearly 20 per cent.; but he did not think that was more than had been effected upon other works, as the result of better appliances, and the application of larger capital. The admirable spirit in which this Paper was written was highly commendable; and if it had been prepared by Mr. Bouch himself, the comparison between the different works could not have been more fairly stated. This evinced such a desire to elicit real truth, that the Author was deserving of great praise. With regard to the use of either iron, or wood, or brick for structures of this description, the decision must entirely rest upon the judgment of the Engineer. There were circumstances in which timber structures were obliged to be erected, as ancillary to other designs. In Norway, viaducts of 90 feet and 100 feet in height had been constructed of that material, in the readiest manner, and with great economy, where they were afterwards to be replaced by embankments. It would appear from the statement of the Author, that under the particular conditions with which Mr. Bouch had to deal, iron was the most suitable material for those works, which were simple, substantial, and free from undue motion; and looking at the cost, it showed that economy of material had been carefully considered. The Paper brought out facts of great practical value, and gave data for the construction of extensive viaducts. This information could not fail to be useful to Engineers, when they were called upon to design works of this description.

Mr. **Bouch** said, the subject had been dealt with in so fair and comprehensive a manner, as to leave but little room for remark.



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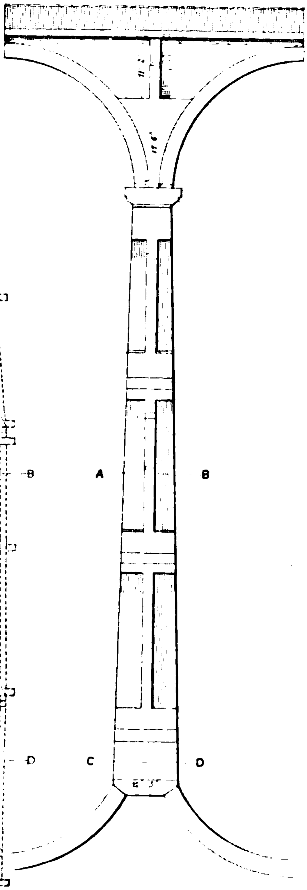
SIDE ELEVATION OF
CENTRE PIER.



CROSS SECTION OF
CENTRE PIER.

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With regard to the comparison which had been made between the Hownes Gill viaduct and the iron structure, he thought that there were no points of analogy between the two works. He quite agreed that the brick structure described in the Paper was a proper one in that particular situation; but in the other case the circumstances were so changed, that neither brick nor stone could have been used. The Hownes Gill viaduct was designed for a railway which had already been many years in operation. There were thus facilities for the conveyance of the materials, which were procured in the district, on the most favourable terms, as the viaduct was to be built for the owners of the railway. Therefore, if he had again to design that bridge, he should adhere to the plan that had been adopted. But in the case of the two iron viaducts on the South Durham and Lancashire line, the circumstances were entirely different. At Deepdale, there was a cutting of 200,000 cubic yards, which could not be commenced till the viaduct was completed, as the whole of the material had to be carried across the valley, to form an embankment on the other side; while at Beelah, there was a cutting containing 50,000 cubic yards of rock, which also had to be taken across the bridge, and could not on that account be commenced until the viaduct was built. Those were circumstances which weighed with him, in estimating time as money, and as railways must be treated as commercial enterprises, the delay of a few years in their construction might be sufficient to condemn an undertaking. It was therefore necessary, without reference to cost, to adopt some form of structure which should enable the line to be completed within a reasonable time. Although in the immediate vicinity of both works there was a vast quantity of stone, yet it was only on one side of the Gills, for on the other side, especially at Beelah, he scarcely knew any district in which stone was so scarce. In point of fact, looking at the quantity of stone required for the foundations of the Beelah viaduct, it cost nearly as much as the whole of the ironwork. On the South Durham line, there were a great number of viaducts, many upwards of 100 feet in height, which were built of rubble, after the plan first adopted by Mr. Hawkshaw. Those were the cheapest on the line, and he had built two viaducts upon that plan in Scotland, 80 feet in height, at a cost of £20 per lineal yard for a single line. In all cases he had used stone, where time allowed him to do so, and the material was at hand. In other cases, he had adopted stone piers, with trussed iron girders; but then the iron was merely used to save time, bearing out the remark, that in works of this description no fixed rule could be laid down. He might mention that the sixteen openings of the Beelah bridge were completed in four months, or at the rate of one span per week, including the erection of the piers. In some instances the difficulties with regard to the foundations were the greatest he had ever encountered. The Westmoreland Gills, as they were termed, were nothing more than great cracks in the mountains. There might be rock at the sides of the Gill, giving the appearance of great solidity; but as soon as it was disturbed, it was found to be only débris from the sides, easily set in motion, and with considerable tendency to slip. In fact, there was one large slip close to the viaduct, which carried away a cottage and a smithy, and for a time placed the viaduct in jeopardy. As an instance of the difficulties of the foundations, he stated that, after the railway had been for some months in operation, it was found that one of the columns of the piers, instead of resting upon the masonry foundation to which it was bolted, had the masonry hanging to it. Although express and heavy mineral trains had been running over the line perhaps for months before this condition was discovered, still the work had withstood this test. It was speedily remedied, and he had no fear that it would occur again. It was but fair to the contractors to add, both as regarded the Hownes Gill viaduct, and the Deepdale and the Beelah iron viaducts, that as examples of good workmanship he believed they could not be surpassed.

Mr. Sheilds thought the comparison between the cost of a brick viaduct and of an iron one was hardly fairly put. In his opinion, in almost all cases, except under extraordinary circumstances, an iron viaduct of the dimensions referred to, could be erected more economically than one of masonry. He did not mean to say that either in durability, or in solidity, an iron viaduct was superior to one of masonry, provided the foundations were good; as a more rigid structure could be formed of masonry than of iron girders, which always involved a greater amount of deflection and vibration, and probably therefore of comparative instability; but for various commercial and practical considerations, he thought iron was generally superior to masonry for this class of structures. For instance, in the comparison made by the Author, the brick structure in question was estimated to cost £20,681, whereas it was calculated that an iron one could be erected in a similar situation for £16,249, or with a saving of one-fifth. Moreover, in considering the prices on which these estimates were founded, it must be noticed that the bricks were obtained on favourable terms, both as regarded first cost and delivery, whilst the ironwork was taken at £22 10*s.* per ton, which, in the present day, was certainly a high rate. Under these circumstances, he believed the saving in first cost by the use of iron would be considerably more than had been stated. The fact that large quantities of bridge ironwork were sent to India, Spain, Russia, and the most distant parts of the world, even where masonry work was cheap, was an argument in favour of the superior advantages of iron structures for large bridges, as it was reasonable to suppose that cost was an important element in these cases.

Mr. BIDDER could not allow the observation to pass unnoticed, that the large extent to which ironwork was sent to India and other places was a proof of its superiority to masonry. That was a mistake; and indeed it might just as well be said, that iron girders were used in the Charing Cross Bridge, because they were cheaper than brickwork, whereas it was well known that that plan of construction was adopted, in order to avoid increasing the height of the railway. Ironwork was sent to India, not on account of its economy over brickwork, but to serve a particular object—in other words, to keep down the level of the railway over the rivers where brickwork could not be applied without raising the railway to an undue height.

Mr. SHEILDS said he had referred to cases in his own practice, where the cost was calculated, and where iron was selected solely for the purposes of economy. There was more scope for economically designing a large viaduct in iron than in masonry; as the spans could be made much wider in the former material. Of course the greater the openings, the fewer would be the piers, and vice versâ; and when the piers were of great height, it was important to diminish their number by enlarging the spans; which could be done more easily and cheaply with iron girders than with arches of masonry. Keeping this in view, it would be seen, that when the cost of a pier, and the weight of ironwork for girders of various-sized openings, were known beforehand, it would be easy, by a trial and error process, to arrive at a minimum of cost for the piers and girders together forming the whole bridge, and he repeated that his own experience had proved to him that ironwork, except under peculiar circumstances, could be erected at a cheaper cost than masonry, in a viaduct such as that referred to in the Paper.

Professor POLE said, that having sent out large quantities of material for Indian railways, he could state that one great reason for the large use of iron upon works of construction in that country, was the saving of time. On the greater part of the East Indian line, for example, brickwork was the natural material of the country; both bricks and labour were very cheap, and the work could be well executed by the native workmen at a cost much lower than in Europe. But there was found to be a limit to the quantity of bricks which could be made in a given time, and as the nature of the country required bridges and flood-works of enormous extent, it soon became evident that if all these were to be constructed of brickwork, the completion of the line must be delayed to an almost indefinite period. For this reason, it was the interest of the company to send out large quantities of ironwork, at an expense much greater than need have been incurred, if the normal material of the country could have been used.

Mr. W. H. BARLOW concurred in the remark, that no rule could be laid down, as to the material of which viaducts should be constructed. He was at present constructing a line of railway upon which there were several viaducts of considerable extent; and in all ordinary cases he had found simple rubble to be the cheapest and the best. But for skew bridges, and under some other circumstances, iron could be used with advantage. He did not think that, at present, either iron or stone could be said to be the cheaper material for viaducts; the choice must be governed by the locality.

Mr. JOHN FOWLER, V.P., said, it was difficult usefully to compare ironwork with masonry, unless all the circumstances were stated in great detail. He had seen the Hownes Gill viaduct, and could pronounce it to be a most substantial work. The dimensions were of the ordinary kind, the material was good, and the foundations were carried down according to the nature of the ground. There was, however, one peculiarity upon which further information was desirable; that was the remarkable spread of the piers, by means of the buttresses. This was carried to a greater extent than he had ever known in a viaduct of similar dimensions. The piers had been extended, laterally, to nearly three times their length at the springing of the arches. He should be glad to know whether the object was to give greater base to the foundations (which he presumed must be the case), and for architectural effect, or whether it had been done with reference to the vertical stability of the piers, which he could scarcely think necessary. The buttresses were certainly not, primâ facie, a necessity for the stability of the work, or for its appearance, and they must have involved considerable additional expense. As to recesses, or openings, in piers, the question, whether desirable or otherwise, must always depend upon the nature and value of the materials used.

Mr. J. SCOTT RUSSELL said, in the bridge aqueduct of Roquefavour,[1] on the line of the canal of Marseilles, there was the peculiarity of the buttresses spreading very much at right angles to the centre line; but the piers were perfectly parallel and vertical on their inner faces. In the Hownes Gill viaduct there was an increase in the dimensions both ways, which required to be accounted for.

Mr. BOUCH remarked, that the lateral spread of the piers was to secure a greater area for the foundations. As the piers were only 12 feet in length at the springing of the arches, and the height of the loftiest ranged from 110 feet to 114 feet, he thought buttresses were necessary to give steadiness to the structure. As a proof that this view was agreed in by other Engineers, it was only necessary to refer to the fact, that inverts had been added to the original design, in order to give a larger base.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xiv., p. 190.

Mr. CUDWORTH said, with regard to the remark, that the comparison between the two constructions was not a fair one, he had furnished data from which every one might form their own conclusions, and thus be enabled to judge how far he had been justified in the observations he had made.

No. 1,051.—"On the Use of the Timber of the Palmyra Palm in the Construction of Bridges." By HENRY BYRNE, M. Inst. C.E.

THE well-known fact, that all trees of the palm tribe contain a mass of pithy fibre in the centre of the stem, (the woody and useful portion being thus reduced to the condition of a mere pipe or tube,) would seem to preclude the possibility of employing such timber in a structure pretending to any degree of permanence, and in which beams are a prominent feature, and framing a matter of necessity. But there are extensive districts in Southern India and in Ceylon, and doubtless in other tropical regions, where no other description of timber grows in any quantity, and where consequently bridges, jetties, &c., must either be constructed with such imperfect material, or dispensed with, if the cost of square timber, and still more of stone or brick, be an object of serious consideration.

The tract of country at the northern extremity of Ceylon, known as the Jaffna peninsula, a district of the province of which the Author had charge till recently, as Resident or Assistant Civil Engineer, is thus circumstanced: Intersected in various directions by tidal inlets, its wants as to means of communication, and especially of bridges across these inlets, (which are of considerable width, and fordable only by foot-passengers and not always without risk,) far exceeded the pecuniary means that could immediately be devoted to it out of the colonial treasury, when the Author took charge of the province. These wants could only be met gradually, by adopting the least expensive plans, consistent with efficiency, that could be devised. Obviously, then, timber piled bridges, of the most simple form, were the best adapted to all the circumstances; and the only question to be decided was, what description of timber should be used. The Jaffna district, embracing an area of about 400 square miles, does not produce, in any quantity, such timber as admits of being squared, and the little that there is, can only be procured in short lengths, and of small scantling fit, merely, in fact, for verandah-posts, wall-plates, door-frames, and similar purposes; while imported timber of large dimensions is as costly as it is in England. But, on the other hand, it abounds with cocoa-nuts and Palmyra palms, the first of which is seldom to be found straight for any considerable length, and is in all other respects inferior as a material for building to the Palmyra. This latter timber was accordingly selected, as the only fitting material which the circumstances admitted of being used.

This palm, known to botanists as the *Borassus flabelliformis*, grows to a height of about 60 feet, of which, however, the lower half only contains sufficient woody fibre to render it useful. It grows perfectly straight, and is of nearly uniform thickness, about 10 inches, from a few feet above the ground. In good specimens the woody portion of the tree, at a height of about 30 feet, is from 3 inches to 4 inches thick, or one-third of the whole diameter of the stem; while at the base there is little or no pith, but the timber is somewhat less hard and compact than higher up, where the interior is of a more decidedly pithy character. The specific gravity of the best portion of the stem is, on an average, 1·055, and its power of resistance to a transverse strain is, as compared with teak, as 9 to 8. A well-grown tree will yield a pile of 30 feet in length, requiring only to be stripped of its outer integument, sometimes, but erroneously, called the bark, and pointed to fit it for use. So compact is the woody fibre, that the Author has never had occasion to ring the top of a pile, in order to secure it from splitting in the process of driving, while the nature of the ground is such as to render shoes unnecessary.

For roadway bearers, the most efficient plan is to split the tree in half, and, after removing the pith, to join the two halves together by wooden keys, at intervals of about 4 feet, and when fixing them to place them on edge. Such beams would be 8 inches deep, and about 6 inches or 7 inches in lateral thickness; too small a scantling certainly to sustain a heavy weight, unless supported at short intervals; but five lines of such bearers, under a roadway 15 feet wide, supported at intervals of 10 feet, are sufficient for the heaviest turnpike road traffic, including the largest elephant waggons. For planking, the trees are usually split into three, yielding planks 6 inches wide, and from 2½ to 3 inches thick. In every case, the roadway bearers were supported directly by piles. The plan of strutting them from the piles, or of supporting them by iron tension-rods, in order to afford wide bays, is objectionable. The first because it would involve either the weakening of the piles, by notching them to receive the struts, or the use of iron bolts and straps, which corrode very rapidly in that climate, and injure the timber in contact with them; and the second, because the safety of the structure would depend solely upon the iron, and become a source of constant anxiety, from the perishable nature of that material. Besides it is not necessary, in any case, to provide bays of greater width than will suffice for the passage under the bridge of a fisherman's canoe, or catamaran, while the additional cost of piling, at such short intervals as 10 feet, is not worth considering.

It may be objected that the roadway platform is not adequately connected with the piling, and that its security is left dependent on its dead weight. But this is found to be quite sufficient in most cases, for the piles are not liable to disturbance by the shock of heavy boats and barges coming in contact with them, and the roadway bearers are generally at too high a level to be reached by floating bodies during floods. In one case only, where such a bridge was constructed across the mouth of an inlet exposed to a heavy surf, was it necessary to strap the roadway bearers down to the piles.

The inexpediency of employing iron in the construction of these bridges, where it was possible to avoid it, has been already referred to; and accordingly, as a rule, it has only been used for spiking the planking to the roadway bearers. There is no objection to its use in this way, for it is sufficiently protected from damp by the concrete usually laid over the planking.

As to the durability of such bridges, it is only necessary to state, that the first the Author constructed has stood for sixteen years without requiring any repairs, beyond the occasional renewal of handrail bars, when wantonly destroyed. It is now in perfect order, except a few of the piles, which were originally of an inferior quality of timber. In the most favourable situation it is believed the average duration of a Palmyra timber bridge may be reckoned at twenty-five years, and even then a large proportion of the material would be found fit for use in the reconstruction of it. The piles are the most liable to decay, perhaps in consequence of their containing so much pith. The natives make a point of removing the pith from all Palmyra timber before storing it up, in the form of rafters and planks for sale, alleging as a reason, that the decay to which the pith is liable is readily communicated to the hard woody fibre. There is probably some justice in this, and it might be worth while, in the case of piles containing much pith, to bore out the centre and fill it with some composition, of which tar or pitch should form a chief ingredient. But a little experience in selection, and a knowledge of the localities which produced the best trees, soon enabled the Author to procure piles containing little or no pith, and he has occasionally met with trees which contained absolutely none for about 20 feet of their length. This timber seemed to be proof against the attacks of the teredo, and even inferior specimens remained perfectly sound below the water-line, while above it a coating of tar was all that was needed to prevent splitting from exposure to the sun.

The following statement of the actual cost of 20 lineal feet of a bridge constructed wholly with Palmyra timber, 300 feet in length between the abutments, and 15 feet wide between the handrails, may be taken as a fair average, though some of these bridges have cost from 15 to 20 per cent. less.

	£.	s.	d.
6 piles at 5s. each	1	10	0
2 transverse bearers, 21 feet, at 6s.	0	12	0
5 longitudinal roadway bearers, 20 feet, at 6s.	1	10	0
45 roadway planks, 15 feet, at 1s. 6d.	3	7	6
100 running feet of handrail bars and posts, at 1d. per foot	0	8	4
36 lbs. iron spikes, at 4½d.	0	13	6
Construction of 20 feet of bridge, at 7s. 6d. per foot lineal	7	10	0
Contingencies	1	0	0
Total	£16	11	4

or 16s. 6d. per running foot.

The practical value of such apparently unpromising material as Palmyra timber, in a district unprovided with bridges, and too poor in money and all other resources to afford the luxury of scientific display, or to admit of the slightest indulgence on the part of an engineer in what has been called the pride of construction, will be manifest on a comparison between the cost of such bridges as the Author was thus forced to build, and of such as he might have been tempted to build had square timber been at hand. In the interior and southern parts of the Jaffna province, where the forests abound with fine timber, and the Palmyra is unknown, or at any of the chief sea-coast stations, where square timber is readily procurable and Palmyra despised, except for roofing purposes, the cost per running foot of a piled bridge of the dimensions stated would not be less than £6, or nearly eight times greater than that of one constructed of Palmyra; so that in the district referred to, instead of an aggregate length of about 2,000 feet of bridges which have been built within the last few years, not 300 feet could have been built for the sum actually expended; if indeed the supposed necessity for using squared timber would not, from its great cost, have precluded the attempt to improve the means of communication through the country, or led at least to its indefinite postponement.

The Paper is accompanied by a Drawing, showing the mode of construction adopted, and by a Model with specimens of the timber employed.

[Mr. John Bethell

Mr. John Bethell remarked, that this timber, from the specimen exhibited, presented an extraordinary appearance. When he first saw it, he fancied it was a piece of creosoted wood. It would be observed that there was a dark substance in the grain, like regular streaks of creosote, such as would appear in young wood which had been subjected to that process; whilst in the heart wood there was nothing of the kind; and it was a question in his mind, whether this palm was not impregnated with some natural bitumen, or resin, which had been drawn up from the earth, and travelled with the sap into the younger layers. In the green heart timber of Demerara, which, in many cases, acted like creosoted wood in resisting the attacks of the worm, the pores were infused with a sort of resinous bitumen, and the wood itself burnt like a torch. He believed that if the Palmyra palm were analysed, it would be found to be of a similar character, and he had no doubt that it was more inflammable than ordinary woods. It was the practice of Engineers to require that sleepers should consist entirely of heart wood, and that the young wood should be cut off, and then such sleepers were sent to be creosoted; but he invariably declined to undertake it, because it was quite impossible that heart wood could be properly creosoted. If Engineers considered heart wood uncreosoted was more valuable than young wood charged with creosote, well and good. Any one, however, who knew the way in which a tree grew, was aware that the external pores remained open, whilst the internal pores were choked up, by the deposit of ligneous matter on the descent of the sap, so that the pores could not afterwards be charged with any artificial bituminous matter. Of the specimens of Scotch fir sleepers creosoted, which were laid on the Great Eastern Railway in 1841, 80 per cent. were still doing duty in the permanent way. On examining one specimen it was found that, while the outer portion which showed the dark colour of the creosoting was perfectly sound and hard, the interior portion or heart of the wood had begun to decay. The rot had commenced in the heart wood, because it had not taken the oil. So in the case of the specimen of the palm now exhibited, the heart wood was decayed already, and might be picked away with the finger, whilst the outer portion was sound and hard.

Mr. J. Scott Russell remarked, that there were two kinds of trees of totally different and opposite natures in their growth; one class taking their young wood from the inside, and another class taking young wood from the outside. These were called by botanists, in the one case endogenous and in the other exogenous. The specimen of wood of the Palmyra palm tribe was no doubt of the endogenous class. The former kind had its hard wood in the centre and the soft wood on the outside; while the other had its hard and old wood on the outside, and the young wood gradually filled up the inside, until it became perfectly solid at the centre, when it was in its highest degree of maturity. He believed that would explain the apparent contradiction between the two kinds of timber, and their relative density at the skin and the heart.

Mr. C. H. GREGORY, V.P., said, the Author had directed attention to the convenience of employing native timber for works of economical construction in the island of Ceylon. In many countries there were other reasons to induce the use of native unprepared woods, in preference to timber imported from Europe, and prepared by the processes in common use to prevent decay. English Engineers had found the advantage of these preparations, especially of creosoting when properly applied, with the soft pine woods used in this country. He had known cases where creosoted timber lasted for so long a period, that it became fairly worn out mechanically, without showing any signs of decay. In tropical climates the circumstances were different, and his experience led him to know, that there were climates where carefully prepared soft European timber would not stand. On the Pernambuco Railway sleepers of pine timber creosoted were used for a considerable time; but in a few years they had become seriously deteriorated by decay. He had examined into the cause of failure, and as far as the most reliable evidence went, he came to the conclusion, that the wood had been well and properly prepared, the process having been conducted by highly-respectable houses, under the most careful and trustworthy inspectors, and he could only suppose, that the creosote had been drawn out of the wood by tropical heat and moisture. He had, therefore, adopted sleepers of native woods; and in Brazil, Ceylon, and other tropical countries, there were woods which, when carefully selected, would withstand all variations of climate, as well as the ravages of the white ant, the dangers from which he believed were not so great as was generally supposed in sleepers, as it was found that the white ant did not attack timber which was frequently shaken.

Mr. POLE said, he was scarcely prepared for the statement in the Paper, that the transverse strength of this palm-wood was greater than that of teak, which was one of the strongest woods known. He did not think this could really be so; but he conceived the impression might have arisen from the fact that, in these endogenous woods, the strongest and best part of the fibre was on the outside, and was therefore in the most favourable position for transverse strength, when an experiment was tried on a whole tree.

Mr. DOYNE said, he had met the Author in Ceylon, and could bear testimony to the great value of the works carried out by the Department with which Mr. Byrne was connected, which had resulted in that island being better provided with roads than almost any other colony under the British Crown. Great judgment had been displayed in the erection of simple and economical works. The facilities and the amount of money at command were not large, and the greater credit was therefore due to the Department for the works that had been carried out, more particularly in the providing of good roads. The tree which had been referred to grew like the cocoa-nut and all other palms. It was virtually a shell containing pith, like the alder tree of this country. That portion which had been alluded to as being decayed was pith, and might be cut out without lessening the strength of the tube. The bamboo was used to a great extent in Ceylon, and though not more than about 4 inches in diameter, with a tube only ½ an inch thick, it was surprising the weight it would carry; the hardness of its texture being such as to resemble horn rather than wood.

December 2, 1862.

JOHN ROBINSON M'CLEAN, Vice-President,
in the Chair.

The following candidates were balloted for and duly elected:—GEORGE BRUNTON, CHARLES DEAN, WILLOUGHBY CHARLES FURNIVALL, JOHN EDWARD HARTLEY, THOMAS LOVELL, MARTIN SAMUELSON, JOSEPH FRANK STRONG, and JOHN TAYLOR, as Members; JOHN BROWN, THOMAS GAUL BROWNING, CHRISTOPHER JOSEPH CATO, AUGUSTO TEIXEIRA COIMBRA, WILLIAM HENRY CUTLER, JOHN FERNIE, MAJOR JOHN CHARLES HARRIS, B.E., FRANCIS ADOLPHUS SMART, and JOHN WADDINGTON, as Associates.

No. 1,076.—"On some of the Internal Disturbing Forces of Locomotive Engines."[1] By ALEXANDER WOODLANDS MAKINSON, M. Inst. C.E.

GREAT and successful efforts have been made of late years to improve the permanent way of railways. In any case of accident arising from an engine leaving the rails, the state of the permanent way first engages attention; and the occurrence of numerous accidents of this nature, and the consequent public inquiry and criticism, have stimulated engineers to effect great improvements in the permanent way. Notwithstanding, however, the high state of perfection to which it has been brought, engineers of eminence have denounced high speed on railways as dangerous, to the extent even of justifying, or demanding, Government interference for its prohibition. The Author ventures to hope, that he may further the progress of engineering practice, by an attempt, not to divert the attention of engineers from the efficient maintenance of the permanent way, but to direct it more to the construction of the locomotives using that way.

In the great problem then, of the safe transit of passengers at the high speeds called for on trunk lines, have the locomotive engineers done their part, by putting on the permanent way, engines without any internal disturbing forces tending to make them leave the rails? May not a modern locomotive engine be accurately described, as an engine intended to move only in a forward direction, but which, from the imperfect arrangement of its parts, is subject continually to erratic and transverse movements from forces generated within itself, and expended destructively on the permanent way; so that it is, when in motion, continually striving to escape from the rails, and is not so much the passive recipient of blows, originating in the imperfections of the permanent way, as it is, in a far greater degree, the ceaseless active agent in inflicting blows on the permanent way, these blows, of course, in their reaction, recoiling on itself? To answer these questions, the Author has endeavoured, by the diagrams shown on Plates 2 and 3, to exhibit graphically the different forces acting on the locomotive when in motion: or neglecting only such as tend to give a disturbing motion vertically.

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[1] The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

It will assist in appreciating the disturbing and objectionable action of these forces, if the consideration of them be premised, by a short statement of the forces which are essentially required in the locomotive. A locomotive engine is intended to move, and exert a tractive force, in a direction parallel to the rails on which it moves: and as, at a given speed, and on a given gradient, (other accidental circumstances, as wind, state of rails, &c., being the same) the resistance is constant, and (except on curves) equal on both rails,—the tractive force, or resultant tractive force of the engine, ought to be exerted in the central longitudinal section of the engine: *i. e.* midway between the rails; otherwise it will, in conjunction with the resistance of the train, which does act in the central longitudinal section of the engine, produce, or tend to produce, in the engine, a motion of rotation, transverse to the direction of its intended motion. Moreover, since the resistance is constant in amount, the tractive force ought as far as possible, to be constant, or liable only to trifling fluctuations, so as to reduce the strain on the working parts of the engine to the minimum.

Returning to the diagrams, in assigning numerical values to the forces under consideration, it was requisite to take some one engine as a type of the modern locomotive: for this purpose, the 'Great Britain' locomotive of the Great Western Railway has been selected, of which indicator diagrams are given in Mr. D. K. Clark's "Railway Machinery." In this engine the length of stroke of the piston is 24 inches, and the diameter of the driving wheels is 8 feet.

Diagram No. 1, Plate 2, from which all the other diagrams are constructed, shows three indicator diagrams taken from this locomotive, at the velocities of 26, 35, and 52 miles per hour respectively. The base, or horizontal line, is the length of the cylinder, 24 inches. The effective steam pressures per square inch of piston, shown by the vertical lines, are given at every inch of the stroke.

Diagram No. 2 shows the effective steam pressures when reduced to the path of the crank pin. The formula showing the ratio between the steam pressure in the cylinder and the equivalent pressure at the crank pin is given in the Appendix No. 1. The effective steam pressures, shown on Diagram No. 2, bear a constant ratio to the tractive force exerted at the rails, and therefore show the variation in the amount of tractive force developed in each cylinder, throughout both the forward and the backward strokes. It is here necessary to remark, that in this Paper, by the forward stroke is meant the stroke of the piston made in the direction of the motion of the train; and by the back stroke that made in the opposite direction to the motion of the train.

But the steam pressures, although the only forces applied to the locomotive, and applied with the object of producing motion in one straightforward direction only, are not the only forces operating on it when in motion; nor are these steam pressures effective only to produce motion in one direction. Other forces are developed, by the *vis inertiæ,* and the varying velocity of some of the parts of the engine, relatively to the main body, or mass of the engine. These forces are fully recognized, and have been happily named "disturbing forces:" the definition of a disturbing force being—a force which impresses, or tends to impress, on the engine some other motion on a horizontal plane, than that simply progressive, straightforward, and equable motion along the rails, which alone is required. These disturbing forces may be divided into two classes:—First, those which are generated by the revolving parts of the engine, as the crank, crank-pin, and half the weight of the connecting-rod; and secondly, those which are generated by the reciprocating masses, as the piston, piston-rod, cross-head, and half the weight of the connecting-rod, &c. In the Appendix, No. 2, an investigation and formula are given to determine the amount of the first class of these disturbing forces—those arising from the revolving appendages of the locomotive. This examination shows their equality with the horizontal component of the centrifugal force; but as it is understood by the Author that, in the practice of the best locomotive engine-makers, the proper counterbalance for these, the revolving appendages, are now always applied, so as to entirely destroy the disturbing effects produced by them, they will, after this mention of their existence, be no longer referred to in this Paper. But the other class of disturbing forces—those generated by the relatively varying velocity of the reciprocating appendages—are not, as the Author believes, met by any counterbalance, but remain as a feature, and as disturbing forces, in by far the largest proportion of the locomotives now running. The Appendix, No. 3, contains an investigation and formula for the amount of this disturbing force.

Diagram No. 3 exhibits graphically the amount of the pressures generated, referred to the square inch of the piston, in the case of the 'Great Britain' locomotive, in which engine the weight of the reciprocating parts on each crank is taken at 495 lbs. The pressures are referred to the path of the crank-pin, and are given at every inch in that path, both for the backward and the forward strokes, at the velocities of 26, 35, and 52 miles per hour respectively.

It is now proposed to examine, somewhat in detail, the nature and origin of these forces. If the piston be supposed to be on the point of commencing the forward stroke, it is then, relatively to the engine, at a state of rest; and has the same absolute velocity V as the engine. Let W represent the weight of the piston, piston-rod, and one half of the connecting-rod; then U, the accumulated work residing in the reciprocating appendages, when the piston is just commencing its forward stroke, $= \frac{\frac{1}{2} W}{g} V^2$, by the well-known formula. But as the piston advances in its stroke, its absolute velocity V_1 becomes greater than V, and continues to increase until the crank arm is vertical, or nearly so; and the amount of work accumulated, or stored up, in the reciprocating parts goes on increasing. During the first half of the front stroke therefore, the reciprocating appendages increase their store of accumulated work; such increase of accumulated work absorbed by them, has been abstracted from the store, or total amount of accumulated work in the mass of the engine; and the effect of such increased accumulation of work in the piston, during the first half of the forward stroke, on the main body, or mass, of the engine, is such as would be produced by a resistance to the train. During the latter part of the forward stroke, the velocity of the piston diminishes; the work stored up in it therefore diminishes, and to the extent of such diminution, becomes available for, and is expended in, the traction of the train; so that for the second half of the forward stroke the effect of the disturbing forces is to develope pressures assisting the motion of the train. The same may be said during the former half of the back stroke; during which the absolute velocity V_1 of the piston, &c., keeps diminishing, until it acquires its minimum value at, or near the mid-stroke. During the latter half of the back stroke, the velocity of the piston, &c., again begins to increase; it again becomes an absorbent of work—to such an extent diminishes the work available for the traction of the train, and produces on the body of the engine the same effect as a resistance to the train. Thus, the *vis inertiæ* of the reciprocating parts, and their varying velocity relatively to the body of the engine, makes them distributors of force, sometimes absorbing, and sometimes yielding it up; and giving rise coincidently to pressures against, or in favour of the motion of the train; now deducting from, and now adding to, the available tractive force of the engine. If the circular path of the crank-pin around the axle be divided vertically, by a straight line through its centre, then the crank-arm will approximately coincide with this line, when in its position of greatest, as also when in its position of least velocity; and while the crank-pin moves through 180°—from its position of greatest to its position of least velocity—the reciprocating appendages develope pressures in favour of the motion of the train; and while the crank-pin moves through 180°—from its position of least, to its position of greatest velocity—the reciprocating appendages develope resistances to the motion of the train. Referring to Diagram No. 3, it will be seen that, in the 'Great Britain' locomotive, at the velocity of 26 miles per hour, the *vis inertiæ* of the reciprocating parts throws a pressure, referred to the path of the crank-pin, against the motion of the train, of 16 lbs. per square inch of piston at the commencement of the forward stroke, diminishing to zero, at a little beyond the mid-stroke. From thence the pressure becomes one assisting the motion of the train, increasing to 26 lbs. per square inch of piston at the end of the forward stroke. The back stroke commences with a positive pressure, or a pressure assisting the motion of the train, of 26 lbs. per square inch of piston, and terminates with a negative pressure, or a resistance to the train, of 16 lbs. per square inch. Similarly, at the velocity of 35 miles per hour, the forward stroke begins with a negative pressure of 33 lbs. per square inch of piston, and terminates with a positive pressure of 45 lbs. per square inch. The back stroke commences with this positive pressure of 45 lbs. per square inch, and terminates with a negative pressure of 33 lbs. per square inch. At the velocity of 52 miles per hour, the pressures of *vis inertiæ* become far greater in amount per square inch of piston than the steam pressure. Thus, the forward stroke commences with a negative pressure of 70 lbs. per square inch of piston, and terminates with a positive pressure of 99 lbs. per square inch; the greatest steam pressure during that stroke being, as shown on Diagram No. 2, only 57 lbs. per square inch. The backward stroke commences with a positive pressure of 99 lbs. per square inch of piston, and terminates with a negative pressure of 70 lbs. per square inch. In general terms, it will be seen that, at every velocity, the pressures generated by the *vis inertiæ* of the reciprocating parts are the greatest at the end of the stroke, and vanish at, or near, the mid-stroke. The pressure during the second half of the forward stroke, and the first half of the back stroke assisting the motion of the train; and during the second half of the back stroke, and the first half of the forward stroke, opposing the motion of the train. Of course, at every velocity, and in both the forward and the backward strokes, the work done in favour of the motion of the train is exactly equal to the work done against it. The *vis inertiæ* and relatively varying velocity of the reciprocating parts are competent, not to create, but merely to distribute, work.

Diagram No. 4 is formed from Diagrams Nos. 2 and 3, by adding together the steam pressures and the coincident pressures arising from *vis inertiæ.* It shows the variation in the tractive force, developed throughout one stroke of either piston. Comparing Diagram No. 4 with Diagram No. 2, it will be seen that the variation in the tractive force of the engine is much greater than would be supposed, if the steam pressures alone were considered. At the velocities of 35 and 52 miles per hour, it will be seen that in the first half of the forward stroke, as well as in the second half of the back stroke, there is really as much or more work done against, as in favour of the motion of the train; so that all the tractive force required for the traction of the train, through one entire revolution of the driving-wheel, is given out during that half of the revolution which is made coincidently with the second half of the forward stroke, and the first half of the back stroke of the piston; being that half revolution made while the piston moves from its position of greatest to its position of least velocity. During the other half revolution of the driving-wheel, or that made while the piston moves from its position of least to its position of greatest velocity, the work done by the steam in the cylinder is barely equal to the work absorbed by the piston in acquiring that increase of velocity; so that no work during that half revolution is available for the traction of the train.

If there were only one cylinder in the modern locomotive, or if both the cranks were similarly placed on the axle, the consideration of the forces acting on the locomotive might here cease. But as modern locomotives are constructed with two cylinders, with cranks at right angles to one another, the three Diagrams No. 5 are required, to exhibit graphically the total tractive force exerted at any moment by the engine. It is evident how these Diagrams are constructed from Diagram No. 4. The one piston being always in advance of the other 90°, or one quarter the path described by the crank-pin, during one turn of the driving-wheel, or 18·8 inches, it is only necessary to add together every two pressures on Diagram No. 4 which are that distance apart, to get the total tractive force of the engine, at every point throughout one entire revolution of the crank-pin. Diagrams No. 5 then show, the variation in the amount of the entire tractive force of the engine (estimated at the crank-pin) throughout one entire revolution of the driving-wheel, at the several velocities of 26, 35, and 52 miles per hour respectively. The datum line in these Diagrams, is equal to the length of the crank circle, or four times 18·8 inches. The vertical lines above the datum show the amount of tractive force exerted by the engine at every inch of the crank circle. The upper horizontal line is the line of mean pressure, and coincides therefore with the constant resistance to the motion of the train. The wave line is the line of tractive force, and where this lies on the upper side of the line of mean pressure, or of resistance, the space between shows the work done over and above what is required to balance the work of the resistances, and which therefore accumulates. Where the dark wave line crosses and passes below the datum line, as it does in Diagram No. 5, velocity 52 miles per hour, it indicates that no tractive force is there developed in the engine; but that a positive resistance to the motion of the train is then created in the cylinder. It will be seen, that at all the velocities—26, 35, and 52 miles per hour—it is in the second quarter of the path of the crank-pin, or that quarter in which both pistons are decreasing in their absolute velocity V—the one piston making the second half of the forward stroke, and the other piston the first half of the back stroke—that the greatest accumulation of work takes place; and that in the fourth quarter of the path of the crank-pin, or where both pistons are increasing their absolute velocity V—the one making the second half of the back stroke, and the other the first half of the forward stroke—that the least amount of work is developed; or, as happens at the velocity of 52 miles per hour, that an absolute resistance to the train is developed. The Diagrams No. 5, now under consideration, show the tendency of the *vis inertiæ* of the reciprocating parts to produce a fore-and-aft motiòn, as it has been termed, of the engine and train; or, more accurately speaking, a varying velocity of the engine and of the train, throughout each revolution of the driving-wheel; as also, a relatively varying velocity of both. During that part of the revolution, where the Diagrams No. 5 show accumulated work, the engine and train increase their velocity. From the point where the tractive force equals the mean steam pressure, to the point where it becomes zero, or vanishes, the engine and train decrease in velocity. But up to this latter point the coupling-bars between the engine and tender remain 'taut' on their pins, though subject to oscillation with the coupling-spring, from the varying amount of the tractive force exerted by the engine. During that part of the revolution where the tractive force (if it may then be so called) becomes negative, the engine, being then subjected to a resistance developed within itself, will be overtaken by the train, and will be 'buffed' forward by the tender, the coupling-bars being then loose on their pins. When the tractive force again becomes positive, the engine will, as it were, run away from the train, till the coupling-bars again bear 'taut' on their pins; the train, however, still decreasing in velocity till the tractive force is equal to the mean pressure of steam. The same cycle of changes then again commences.

If the history of the locomotive is referred to, it will be found that the early experimenters, Murdoch, Trevithick, and others, constructed their engines with a single cylinder only. The use of two cylinders, with cranks at right angles, was first introduced, in 1811, by Blenkinsop; the presumed advantages being first, certainty of starting, and secondly, uniformity of motion. At the speeds then, and for twenty years after, contemplated on railways, both these important objects were no doubt best secured in the double-cylinder engine. But since that time, the necessities of railway travelling in respect of speed, and the power of engines, have greatly altered. With the aid of the diagrams the Author believes he may clearly establish, that for locomotive engines of the present day, the double-cylinder engine, as generally constructed, has, in respect of the second advantage claimed for it, uniformity of motion, hardly any superiority over the single-cylinder engine, as it may be constructed, even at what may be termed the minimum speed of 26 miles per hour; while at all greater speeds than that, the double-cylinder engine is in respect of uniformity of motion, decidedly inferior to the single-cylinder engine.

Before, however, proceeding to make this comparison, it is proposed to complete the examination of the disturbing forces at work in the modern locomotive. Hitherto, only the disturbing effect of these forces, in their tendency to produce a fore and aft motion, has been considered. But their most prejudicial effect is in their tendency to produce a sinuous motion, primarily in the engine, and thence communicated to the train—a tendency to move transversely to the rails, first to the right hand, and then to the left. In considering this tendency to produce sinuous motion, it will be necessary to include the steam-pressures in the cylinders, among the disturbing forces. Both the classes of disturbing forces hitherto alluded to—those arising from the revolving and reciprocating parts—are entirely independent of the action of the steam in the cylinders. Their magnitude is determined by the velocity of the engine and the proportions of its parts; and these being the same, remain unaltered whether the engine is running with steam on or steam off. But in the modern locomotive, with two cylinders, and cranks at right angles to each other, the very action of the steam which propels the train may fairly be classed among the disturbing forces of the engine. Its tendency is exactly the same in character as that of either class of the disturbing forces before alluded to. It is only by studying the action of the steam-pressure in its character as a disturbing force—firstly alone, and then as combined, or in its joint action with the other disturbing forces—that the merits or demerits of the modern two-cylinder locomotive engine, with regard to its stability on the rails, its action on the permanent way, its essential resistances, and the wear and tear of parts, can be properly appreciated.

Diagram No. 6, Plate 3, has been prepared to illustrate the disturbing action of the steam in the double-cylinder engine. It has been assumed that the two cylinders are at the distance apart of 5 feet, or one over each rail. The two horizontal lines are supposed to represent the rails, and from each rail as a datum line is marked off, at right angles to it, the pressure exerted by the steam on the crank-pin over that rail at every point travelled over during one revolution of the crank-pin. The diagram thus shows separately the two simultaneous steam-pressures exerted, referred as in the other diagrams, to the path of the crank-pin. The centre of pressure of each pair of simultaneous steam-pressures has been found, and is marked on the diagram by a small black circle. The line joining these centres of pressure, it will be seen, crosses over from one rail to the other, in each quarter of the path of the crank-pin. Only at that point where the line intersects a line midway between the rails, does the resultant steam-pressure, therefore, act in the same straight line as the resultant of the resistances to the train. At any other point these two resultant pressures are parallel, and at a certain distance or leverage from each other. Such a couple of forces tends to produce a motion of rotation transversely to the rail. As the leverage is first on one side of the centre of resistance, and then on the other, so the motion of rotation tended to be produced alternates first to the right and then to the left; and is, in short, sinuous motion. This tendency to sinuous motion in the double-cylinder engine, produced by the steam-pressures, would exist, however perfectly the revolving and the reciprocating parts of the engine were balanced.

Diagrams No. 7 are similarly prepared, to show the tendency to sinuous motion produced by all the disturbing forces. The same assumption is made, as to the distance apart of the cylinders, as in the last diagram. From each rail as a datum line is set off, at right angles to it, the total tractive force developed in the cylinder over it, at every point in the path of the crank-pin. Hence the diagram shows, on every transverse line, the separate pressures acting as tractive force simultaneously developed in the two cylinders, and referred, as in all the other diagrams, to the path of the crank-pin. The shaded part on the diagram indicates, that at that part of the revolution the tractive forces developed, if indeed they may still retain that name, are negative in their character—act, in short, as resistances. It will be seen, that at some points the two pressures acting simultaneously on the engine over the two lines of rail, are acting in opposite directions; so that while one side of the engine is being propelled forward in the direction of the motion of the train, by a positive pressure, the other side of the engine is simultaneously retarded by a negative pressure. This of course produces the sinuous motion in its greatest development. The amount of the pressure thus caused, and tending to throw first one rail and then the other outward has been estimated at the various points in the distance travelled over, in one entire revolution of the driving-wheel, and are exhibited graphically in Diagrams No. 8. The necessary assumptions as to the proportions of the engine are as follows: Distance apart of the cylinders 5 feet, as before; diameter of cylinder 16 inches; distance of the driving-axle, in which the centre of rotation is supposed to be, from the leading axle, where the disturbing force is measured, 6 feet. The amounts of these pressures, tending to drive the leading wheels outward against the rails, are given in pounds. Although the proportions of the engine, taken as the type of modern locomotive, are most favourable for steadiness of motion, yet it will be seen, that the maximum outward pressures of even this engine are considerable. Thus, at a velocity of 26 miles per hour, the maximum pressure is 2,868 lbs., and at 52 miles per hour, 3,942 lbs., or 26 cwt. and 36 cwt. respectively. So markedly have these outward pressures told upon one part of the permanent way, the fastenings of the chairs, that the Government inspectors have lately condemned the use of wooden trenails, and have pronounced iron to be the only fit material to withstand the shocks to which the chair-fastenings are liable.

The wear of the flanges of the leading wheels of locomotives is another evidence of the injurious effects of these outward pressures. Such wear of the flanges shows the wheels of the leading axle to be running always on unequal diameters, whence results sledging, of which the burnished state of the rails furnishes independent evidence. It is to be expected that great waste of power is thus incurred. It is well understood, that the resistance of a train exposed to a side wind is increased something like 15 per cent., and it is conceivable, that the oscillatory motion of the two-cylinder engine will generate alternately on either rail, a resistance similar in nature to that produced constantly on the same side of the engine by a side wind. The continual jarring and vibration of the carriages, which make railway travelling so unpleasant to all, and as medical men assert, decidedly unhealthy in the case of invalids and persons of delicate health, have their rise mainly in the sinuous motion now under consideration, and the sledging and shocks thereby caused. Whoever has travelled on the atmospheric railway, and remembers the gliding, the delightful smoothness, and the steadiness of the motion, will recognize what railway travelling might be, if the sinuous motion and tendency were annihilated. The several cases which have occurred of engines leaving the rails on different lines, on the Great Northern, the North Staffordshire, the South Eastern, the South Wales, and lately on the London, Chatham, and Dover line, had one circumstance in common, high speed of travelling. That, and the absence of sufficient explanation by reason of any defect in the permanent way, point out as their originating cause, the sinuous motion inherent in an unbalanced double-cylinder engine.

What, then, is the practical remedy for the evils here glanced at? The Author ventures to submit, for the opinion and discussion of the members, that the remedy lies in the return, at all events for passenger traffic, to the single-cylinder engine. It will perhaps be conceded, that a locomotive worked by a single cylinder, placed exactly in its mid-section, would not give rise to sinuous motion, and the grave evils attendant thereon. But the objections made, and taken as conclusive, against the single-cylinder engine are, as stated before—a less uniform exertion of tractive force than the double-cylinder engine, and the impossibility of starting at certain parts of the stroke of the piston. Although the great majority of the locomotives now worked in this country are not balanced, so far as concerns their reciprocating parts, yet the necessity for doing so has been pointed out both by French and English writers; and a mode of doing it suggested, by weights applied to the wheels. Without discussing the question, whether this is the best way of balancing these parts, let it be supposed that a single-cylinder engine is thus fully counterbalanced. The disturbing forces of inertia will thus be annihilated, and the tractive power per square inch developed by such a balanced single-cylinder engine will be represented accurately by Diagram No. 2, Plate 2, which is a diagram of the steam pressures referred to the path of the crank-pin. This Diagram shows that the accumulated work per square inch of piston during one stroke of the piston, is at 26 miles per hour 39 units in the forward stroke, and 43 units in the back stroke. But as the supposed single-cylinder engine must have a cylinder equal in area to both those of the two-cylinder engine, it is necessary, in order to make Diagram No. 2 a correct diagram of the total tractive force, to double all the pressures marked on it, and thus 78 and 86 units will represent the accumulated work during the forward and the back strokes of the supposed single-cylinder engine; these amounts measuring its greatest departure from uniformity of motion, at a velocity of 26 miles per hour. Now it might be shown, how insignificant this amount of accumulated work is, compared with the total amount of accumulated work in even a small train moving at that velocity; a locomotive at speed forming in fact a fly-wheel of more controlling power than in any case is thought requisite. But it is preferred to make the direct comparison, which the Diagrams provide for. Thus, referring to Diagrams No. 5, it will be seen that the accumulated work, or measure of departure from uniform motion, in each revolution of the driving-wheel, in the double-cylinder engine of ordinary construction, is—at 26 miles per hour 71 units, at 35 miles per hour 124 units, and at 52 miles per hour 240 units. Then referring to Diagram No. 2, and bearing in mind that, for the purposes of comparison, all the amounts there given must be doubled, it will be seen, that in the balanced single-cylinder engine, the accumulated work is—at 26 miles per hour 86 units, at 35 miles per hour 48 units, and at 52 miles per hour 70 units. So that the uniformity of motion of the single-cylinder engine, compared with that of the ordinary double-cylinder engine, would be at 26 miles per hour less in the ratio of 71 to 86, at 35 miles per hour greater in the ratio of 124 to 48, and at 52 miles per hour greater in the ratio of 240 to 70.

With respect to certainty of starting, it must be conceded that the double-cylinder engine has the advantage over the single cylinder; but the Author hopes to show, that the superiority in this respect is very slight. As the resistance of a train increases rapidly with its velocity, it is evident that a locomotive engine can never be required to exert at starting its full average tractive force. The proportion, however, of this which it may be required to exert at starting will vary with circumstances of load, gradient, &c.; and the only way of making the comparison, with respect to certainty of starting, between the double-cylinder engine and the single-cylinder engine, is, to determine what tractive power the double-cylinder engine is capable of exerting at starting, when starting with its pistons in the most unfavourable position. Suppose, then, the double-cylinder engine, having, when working in full gear, an admission of steam through three-quarters of the stroke, and the steam released at 90 per cent. of the stroke; and suppose the engine to be standing in such a position, that the piston in one cylinder, making the backward stroke, may be at 90 per cent. of its stroke, or a little more advanced; the steam behind this piston is then cut off from the steam-chest, but open to the exhaust. While the engine is standing, this cylinder of steam will be exhausted, and on the starting of the engine will be altogether useless for the creation of tractive power, which can only then be supplied by the other cylinder. If it be supposed that the length of the stroke is 24 inches, and the connecting-rod six times the length of the crank, it will be found that when the piston in the backward stroke is within 10 per cent. of its stroke from the end, the crank-arm is 39⅔° from the horizontal. The other crank, 90° in advance, is therefore 50⅓° from the horizontal, and its piston has advanced 3¾ inches on the forward stroke. The pressure exerted on the piston, when referred to the path of the crank-pin, varies (neglecting the influence of the connecting-rod) as the sine of the angle of the crank with the horizontal. If P be the pressure of steam in the cylinder per square inch of piston, A the area of the cylinder, and n the ratio of the diameter of the driving-wheel to the stroke of the piston, the total tractive force which the double-cylinder engine can exert, when starting from its most unfavourable position, $= \frac{\text{P A} \sin 50\frac{1}{3}}{n} = \cdot 77 \frac{\text{P A}}{n}$. The area of the single cylinder will be 2 A; and the engine will therefore exert an equal tractive power at starting with the double-cylinder engine, when the sine of the angle with the horizontal of its crank-arm equal ·375, which is the sine of 22·3°; or when its piston has advanced about $\frac{7}{8}$ of an inch on its stroke. The dead part of the stroke of a single-cylinder locomotive would therefore be passed, when its piston has advanced $\frac{7}{8}$ of an inch in its stroke, at which time it would be exerting a tractive force of $\frac{375 \times \text{P} \times 2\ \text{A}}{n}$. If the pressure of the steam be equal to 100 lbs. per square inch, and the area, 2 A, of the cylinder be equal to the area of two cylinders of 18 inches diameter, or 520 square inches, the required starting tractive force would be $\frac{\cdot 375 \times 100 \times 520}{4} = 4{,}875$ lbs., which may therefore be taken as the maximum resistance to a passenger train at starting. If, now, the single-cylinder engine be supposed to be starting from its most unfavourable position—that is the position in which the piston would be at the end of the stroke—it is evident that before its crank-arm could be made to describe the angle 22°, or its piston be advanced $\frac{7}{8}$ of an inch in the stroke, there must, by some means or other, be overcome a resistance of 4,875 lbs., through a distance $\frac{22}{180} \times 4 \times 3 \cdot 1416 = 1\frac{1}{2}$ foot, or a total work overcome of $4{,}875 \times 1\frac{1}{2} = 7{,}312$ units. Of the work thus required to be done, before the engine could exert the requisite tractive power unaided to start the train, a certain portion represented by $520 \times 100 \times \frac{\frac{7}{8}}{12} = 3{,}791$ units would be supplied by the steam in the cylinder; so that only $7{,}312 - 3{,}791$, or 3,521 units of work would be required from some external source. Thus, then, to give a single-cylinder engine the same certainty of starting as a double-cylinder engine, all that is required is to put into the hands of the driver, a means of applying to the circumference of the driving-wheel of the engine a maximum pressure of 4,875 lbs., and to exert a certain power, or work, represented by 3,500 lbs. lifted through 1 foot; which quantity of work is generally estimated as the work of one man for one minute, working from six to eight hours per day. This does not appear to be a very difficult mechanical problem.

In conclusion, the Author condenses the foregoing Paper, in venturing to submit for the consideration of the members,—that a single-cylinder engine would be free from all sinuous motion; that at 26 miles per hour, it would have, when counterbalanced, about the same, and at higher speeds, far less fore-and-aft motion than the ordinary two-cylinder engine; that by supplying the driver with the means of applying about as much power as is expended in putting the breaks on hard, the single-cylinder engine would have equal certainty of starting with the two-cylinder engine; that the use of single-cylinder engines for passenger traffic would, by reducing or annihilating the oscillation and vibration of the carriages, render railway travelling less unpleasant; that it would reduce the cost of locomotive power, and the expense of maintenance of permanent way; and that it would lengthen the life of the rails, and lessen the dead weight of the engine, and the wear and tear of its parts.

The Paper is accompanied by a series of Diagrams, from which Plates 2 and 3 have been compiled.

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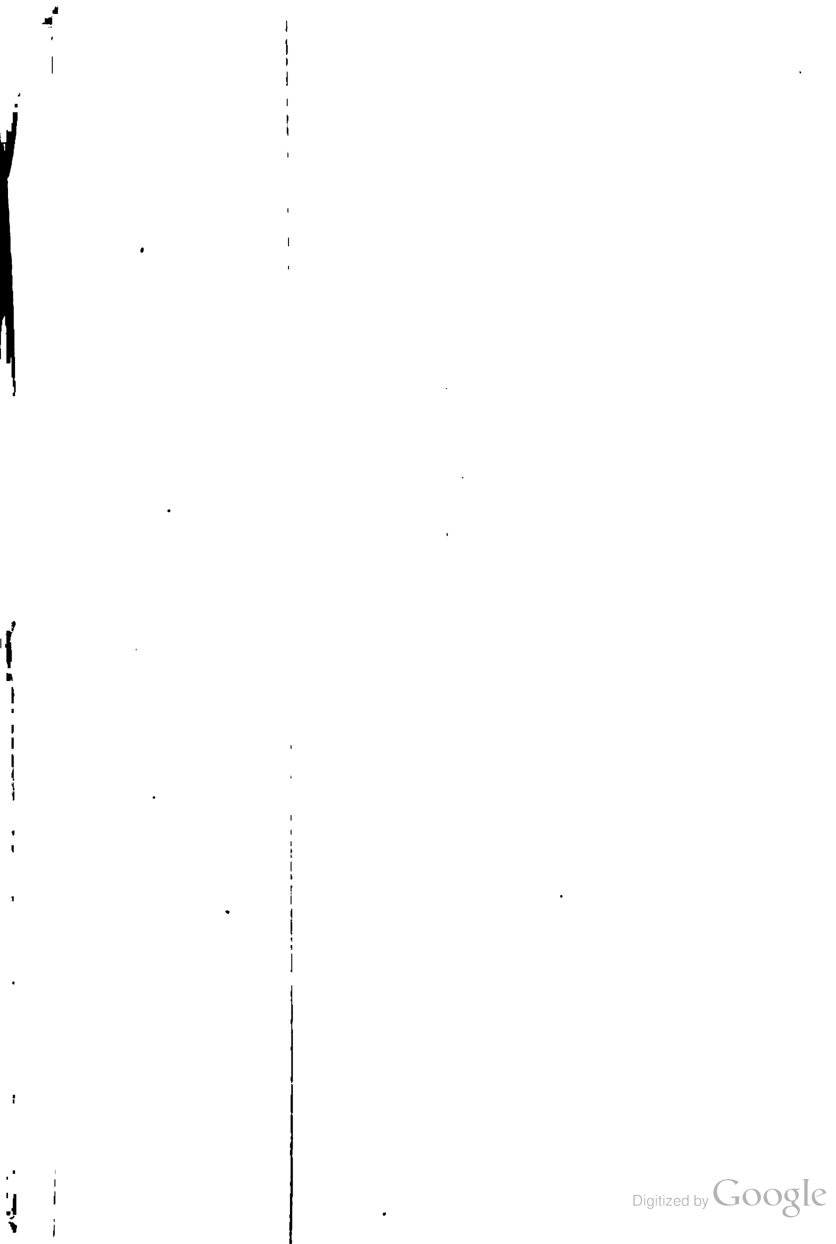
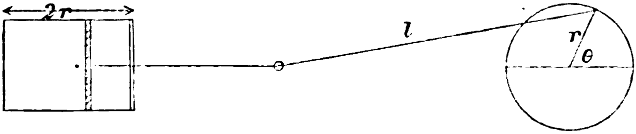


APPENDIX.

No. 1.

FORMULA SHOWING THE RELATION BETWEEN THE PRESSURE ON THE PISTON, AS OBSERVED BY THE INDICATOR, AND THE EQUIVALENT PRESSURE AT THE CRANK PIN.

Fig. 1.



Let P, be the pressure on each square inch of piston.
P_1, the equivalent pressure at the crank pin.
r, the radius of the crank circle.
l, the length of the connecting rod.
θ, the angle which the crank arm makes with the horizontal.

Then, while the crank pin has moved through $r\,\theta$, the piston has moved: –

$$r - r\cos.\,\theta \mp \left(l - \sqrt{l^2 - r^2 \sin.^2\theta}\right) \left\{ \begin{array}{l} \text{for the forward} \\ \text{for the backward} \end{array} \right\} \text{stroke.}$$

Now, let the angle θ be increased by the infinitely small increment $\delta\,\theta$; then while the crank pin moves through $r\,\delta\,\theta$, the piston will move through the differential of:—

$$r - r\cos.\,\theta \mp \left(l - \sqrt{l^2 - r^2 \sin.^2\theta}\right) = \left(r\sin.\,\theta \mp \frac{r^2 \sin.\,\theta \cos.\,\theta}{\sqrt{l^2 - r^2 \sin.^2\theta}}\right)\delta\,\theta$$

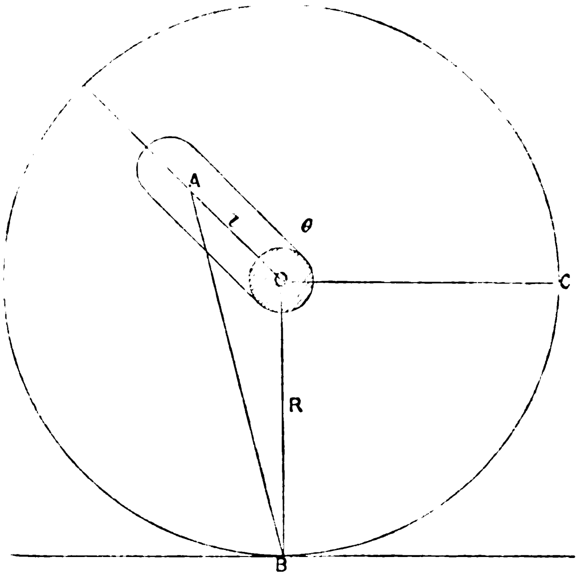
therefore, $$\mathrm{P} \times \left(r\sin.\,\theta \mp \frac{r^2 \sin.\,\theta \cos.\,\theta}{\sqrt{l^2 - r^2 \sin.^2\theta}}\right)\delta\,\theta = \mathrm{P}_1\, r\,\delta\,\theta;$$

and, $$\mathrm{P}_1 = \mathrm{P}\left(\sin.\,\theta - \frac{r \sin.\,\theta \cos.\,\theta}{\sqrt{l^2 - r^2 \sin.^2\theta}}\right) \text{ for the forward stroke of the piston,}$$

$$= \mathrm{P}\left(\sin.\,\theta + \frac{r \sin.\,\theta \cos.\,\theta}{\sqrt{l^2 - r^2 \sin.^2\theta}}\right) \text{ for the backward stroke of the piston.}$$

No. 2.

DISTURBING FORCE GENERATED BY THE UNBALANCED REVOLVING MASSES.



Let A be the centre of gravity of the unbalanced part of the crank, and let I be its moment of inertia about A : and I_1 its moment of inertia about B.

Let l be the distance of A from the centre of the axle.

θ = the angle A O C.

R = the radius of the driving wheel.

Then, the moment of inertia I_1 of the crank about B . . . . (1)

$$= I + \{ (l \cos. \theta)^2 + (R + l \sin. \theta)^2 \} M$$

$$= I + (R^2 + l^2 + 2l\,R \sin. \theta)\,M,$$

where M is equal to the volume of the crank.

Let V be the velocity of the train : then $\frac{V}{R}$ is the angular velocity of the centre of gravity A about B. Then U the accumulated work in the crank . . . (2)

$$= \tfrac{1}{2} \frac{V^2}{R^2}\left(\frac{u}{g}\right) \{ I + R^3 + l^2 + 2\,l\,R \sin. \theta \}\,M.$$

Let θ become $\theta + \delta\theta$, then $d\,.\,U = \frac{V^2}{R^2}\frac{u}{g} M\,l\,R \cos. \theta\,\delta\theta$

$$= \frac{\frac{l^2}{R^2}V^2}{l}\,\frac{W}{g} \cos. \theta\ R\,\delta\theta$$

But $\frac{\frac{l^2}{R^2}V^2}{l}\,\frac{W}{g}$ is the centrifugal force C of the crank, whose weight is W,

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[1] *Vide* " Moseley's Mechanics," page 82.

[2] *Ibid.* page 75.

having its centre of gravity at the distance l from the centre of the wheel:

Therefore, $$d\,\mathrm{U} = \mathrm{C}\cos.\theta\,\mathrm{R}\,\delta\theta;$$

While U thus becomes $\mathrm{U} + d\,.\,\mathrm{U}$, the train moves through the distance $\mathrm{R}\,\delta\theta$: and the increase or diminution of the accumulated work U in the crank, as it describes the small angle $\delta\theta$, has the same effect on the train as a pressure $\mathrm{P} = \mathrm{C}\cos.\theta$ acting against, or in favour of the motion of the train. This equality of P to the horizontal component of the centrifugal force is noticed in Mr. D. K. Clark's Railway Machinery, page 168.

No. 3.

To find the Pressures, referred to the Crank Pin, generated by the Vis-Inertiæ and varying Velocity of the reciprocating parts of a Locomotive in motion.

Let r = the radius of the crank.
nr = the radius of the driving wheel.
L = the length of the connecting rod.
θ = the angle the crank makes with the horizontal.
V = the velocity in feet per second of the train.
V_1 = ditto, ditto, of the piston, not relative, but absolute velocity.

First, for the forward stroke of the piston, or that made in the direction of the motion of the train. While the axle of the driving wheel moves through $nr\,\theta$, the piston moves through

$$nr\,\theta + r\text{ ver. sin. }\theta - \left(\mathrm{L} - \sqrt{\mathrm{L}^2 - r^2\sin.^2\theta}\right)$$

Now let the angle θ be increased by an infinitely small quantity $\delta\theta$; coincidently with this increase, the axle moves through $nr\,\delta\theta$, and the piston through the differential:—

$$d\,.\left(nr\,\theta + r\text{ ver. sin. }\theta - \left(\mathrm{L} - \sqrt{\mathrm{L}^2 - r^2\sin.^2\theta}\right)\right)$$
$$= \left(nr + r\sin.\theta - \frac{r^2\sin.\theta\cos.\theta}{\sqrt{\mathrm{L}^2 - r^2\sin.^2\theta}}\right)\delta\theta$$

The velocities V and V_1 of the axle and of the piston respectively are to one another as the spaces they travel through in the same time:—

Therefore, $$\frac{\mathrm{V}_1}{\mathrm{V}} = \frac{\left(nr + r\sin.\theta - \dfrac{r^2\sin.\theta\cos.\theta}{\sqrt{\mathrm{L}^2 - r^2\sin.^2\theta}}\right)\delta\theta}{nr\,\delta\theta}$$

$$\text{or }\mathrm{V}_1 = \left(\mathrm{I} + \frac{\sin.\theta}{n} - \frac{r\sin.\theta\cos.\theta}{n\sqrt{\mathrm{L}^2 - r^2\sin.^2\theta}}\right)\mathrm{V}.$$

Now let U represent the work accumulated in the reciprocating parts of the engine, the weight of which is represented by W. By a well-known formula:—

$$\mathrm{U} = \tfrac{1}{2}\frac{\mathrm{W}}{g}\mathrm{V}_1^2$$

V_1 has been shown to be a function of θ. Let then θ be increased by the infinitely small quantity $\delta\theta$; coincidently with this increase, the crank pin has moved through a distance $r\,\delta\theta$, and the accumulated work in the reciprocating parts has been increased by the differential $d\,.\,\mathrm{U}$ =

$$d\,.\left(\tfrac{1}{2}\frac{\mathrm{W}}{g}\mathrm{V}_1^2\right) = \frac{\mathrm{W}}{g}\mathrm{V}_1\,d\,.\,\mathrm{V}_1$$

But $$\mathrm{V}_1 = \left(\frac{\mathrm{I} + \sin.\theta}{n} - \frac{r\sin.\theta\cos.\theta}{n\sqrt{\mathrm{L}^2 - r^2\sin.^2\theta}}\right)\mathrm{V}\text{ and—}$$

$$d\,.\,\mathrm{V}_1 = \left(\frac{\cos.\theta}{n} - \frac{r\,(\cos.^2\theta - \sin.^2\theta)}{n\sqrt{\mathrm{L}^2 - r^2\sin.^2\theta}} + \frac{r^3\sin.^2\theta\cos.^2\theta}{n\sqrt{(\mathrm{L}^2 - r^2\sin.^2\theta)^3}}\right)\mathrm{V}\,\delta\theta$$

therefore, $d \,.\, \mathrm{U} = \dfrac{\mathrm{W\,V}^2}{r\,g}\left(\dfrac{\mathrm{I} + \sin.\,\theta}{n} - \dfrac{r \sin.\,\theta \cos.\,\theta}{n\sqrt{\mathrm{L}^2 - r^2 \sin.\,^2\theta}}\right) \times$

$$\left(\frac{\cos.\,\theta}{n} - \frac{r\,(\cos.\,^2\theta - \sin.\,^2\theta}{n\sqrt{\mathrm{L}^2 - r^2 \sin.\,\theta}} + \frac{r^3 \sin.\,^2\theta \cos.\,^2\theta}{n\sqrt{(\mathrm{L}^2 - r^2 \sin.\,^2\theta)^{\frac{3}{2}}}}\right) r\,\delta\,\theta.$$

Now this increase of work d . U, accumulated in the reciprocating parts of the engine, while the crank pin moves through $r\,\delta\,\theta$, has been for the moment abstracted from the moving, or effective force of the engine: or should d . U be negative, it represents the work yielded up by the reciprocating parts to aid the moving forces on the engine. In either case, the moving forces of the engine are diminished, or increased, by a pressure P, which, estimated at the crank pin

$$= \frac{\mathrm{d}\,.\,\mathrm{U}}{r\,\delta\,\theta}, \text{ or}$$

$$\mathrm{P} = \frac{\mathrm{W\,V}^2}{rg}\left(\mathrm{I} + \frac{\sin.\,\theta}{n} - \frac{r \sin.\,\theta \cos.\,\theta}{n\sqrt{\mathrm{L}^2 - r^2 \sin.\,^2\theta}}\right) \times$$

$$\left(\frac{\cos.\,\theta}{n} - \frac{r\,(\cos.\,^2\theta - \sin.\,^2\theta}{n\sqrt{\mathrm{L}^2 - r^2 \sin.\,^2\theta}} + \frac{r^3 \sin.\,^2\theta \cos.\,^2\theta}{n\sqrt{(\mathrm{L}^2 - r^2 \sin.\,^2\theta)^{\frac{3}{2}}}}\right)$$

Similarly for the back stroke $\mathrm{V}_1 = \left(\mathrm{I} - \dfrac{\sin.\,\theta}{n} - \dfrac{r \sin.\,\theta \cos.\,\theta}{n\sqrt{\mathrm{L}^2 - r^2 \sin.\,^2\theta}}\right)$, and

$$\mathrm{P} = \frac{\mathrm{W\,V}^2}{r\,g}\left(\mathrm{I} - \frac{\sin.\,\theta}{n} - \frac{r \sin.\,\theta \cos\,\theta}{n\sqrt{\mathrm{L}^2 - r^2 \sin.\,^2\theta}}\right) \times$$

$$\left(-\frac{\cos.\,\theta}{n} - \frac{r\,(\cos.\,^2\theta - \sin.\,^2\theta)}{n\sqrt{\mathrm{L}^2 - r^2 \sin.\,^2\theta}} + \frac{r^3 \sin.\,^2\theta \cos.\,^2\theta}{n\sqrt{(\mathrm{L}^2 - r^2 \sin.\,^2\theta)^{\frac{3}{2}}}}\right).$$

Mr. M'Clean inquired what mode was proposed for overcoming the mechanical difficulty of starting the train with a single-cylinder engine.

Mr. Makinson replied, that he had devised a means of doing this; but he had not prepared either a model or a drawing of it, as he had proposed in the Paper merely to define the limits of the pressures and forces necessary for the starting of the engine, and so prepare and clear the way for the mechanical solution of the problem. The plan which had occurred to him as a feasible one was as follows:—Two parallel friction discs, having their working faces inclined to each other, capable of being thrown in and out of gear, were pressed upon and gripped between them the two sides of the tyre of the driving-wheel. Pressure applied by the driver to a hand-wheel, and multiplied by proper gearing, turned the friction discs, and with them the driving-wheel.

Mr. Kitson thought the members were indebted to the Author, for his elaborate demonstrations of the disturbing forces which, in his opinion, operated upon the locomotive engine; but as a practical man, Mr. Kitson was not disposed to admit, generally, the correctness of all the data. In the first place, it was difficult to apply theory to the working of the locomotive engine; and he could hardly understand how it was possible to apply all the tests that would be necessary, to enable such carefully tabulated results to be prepared. The chief reason for the introduction of the double-cylinder locomotive was the practical difficulty of starting a train with a single-cylinder engine, a difficulty which he at present regarded as insurmountable, and which was of itself sufficient to cause the idea of a single-cylinder locomotive to be at once dismissed. Another difficulty seemed to have been overlooked by the Author,—that was, that the centre of gravity would have to be raised so high, with a cylinder in the centre, as to create a serious objection, which would counterbalance any presumed advantage of a single-cylinder engine. Nor was he disposed to admit, that the locomotive engine deserved all the blame attributed to it for the lateral motion of the train, as he thought that defects in the permanent way had a great deal more to do with it. With a light locomotive engine it was possible that many of these forces might have a serious effect, in increasing the unsteady motion; but with locomotives of the present weight, the influence of the cylinders upon the large mass was much less than he was prepared to expect, as was shown by the results now submitted. The tendency to produce an oscillating motion by the engine was to a great extent neutralised by its weight, and was not communicated from the engine to the train; but was principally owing to the difficulty of keeping the road in perfect order. Although great pains had been taken in demonstrating, theoretically, some of the results, yet practically he considered the object sought would not be obtained by the reintroduction of the single-cylinder engine.

Mr. T. E. Harrison said, the point suggested, of equalizing the motion of the engine by having a single-cylinder, was tried in another way by the late Mr. Robert Stephenson. An engine was built by him with three cylinders, a large one in the centre and two smaller ones at the sides, and was tested for many years on the North-Eastern Railway. The main object was to avoid the lateral motion. He had constantly ridden upon that engine, and having been in the habit of riding upon other descriptions of engines at the highest velocities, he confessed he had never found any advantage in that respect in the engine to which he alluded over other well-balanced engines. There was no doubt a great difference in the balancing of engines; and one class, known as the Rocking Horse of Kent, with outside cylinders, badly balanced, had caused more accidents from running off the line than any other engines with which he was acquainted. Much depended upon the state of the permanent way, and that could not always be kept in perfect order, subject as it was to variations in the temperature, to changes in the weather, and to other influences. Two things required special attention; first, the permanent way should be maintained in as good order as possible, and in the next place, the balancing of the engine should be rigidly enforced; and here he would remark, that whatever might be professed, he believed engines were not sufficiently put through the test of the weighing machine. When turned out of the factory, the engines were put upon the machine, and the springs were properly adjusted; but when an engine was tested, which had been at work some time, it was often found that, for some reason or other, it was not properly balanced. That was a question simply as regarded the adjustment of the springs, but in the design of the engine he believed sufficient attention was not always paid to the balancing. He had noticed a great difference in engines in respect of their motion, and it undoubtedly was a difficult question, but he could not agree, that by the plan suggested, of using one cylinder only, the steadiness of the engine would be improved; because in the three-cylinder engine to which he had referred, the necessity of raising the boiler, to get in the middle cylinder, caused the centre of gravity to be so high, that all the expected advantage in steadiness was lost, and if a single cylinder was employed the difficulty would be increased.

Mr. Makinson said, in reply to questions, that in Diagram No. 6, the tendency to produce sinuous motion was that due to the pressure of the steam only, without any allowance being made for the momentum of the parts; and that throughout the series of diagrams, the pressure of steam per square inch of piston, referred to the path of the crank pin, was given.

Mr. F. J. **Bramwell** said, the opinion appeared to be entertained. that in this Paper theory and practice were at variance with each other. Now he believed it was a truism, that theory and practice could never be at variance, when the theory itself was perfect and sufficient, *i. e.* worked out so as to embrace all points, and when the practice had been carefully observed and properly reported. In this case there could be but little doubt, that the practice had been carefully reported, for observations had been made by too many men of experience to leave that in dispute. If, therefore, there were in this instance discord between theory and practice, it must arise from inaccuracy in the theory, and not from imperfect appreciation of the practice. He would briefly state what he considered the inaccuracies were in the present Paper. The disturbing forces had been divided by the Author into two classes,—those which arose from the pressure of the steam in the cylinder propelling the engine,—and those which arose from the momentum of certain parts,—and it would be convenient to keep to that classification. With regard to the former, and assuming the parts to be without weight and without momentum, he understood the Author put forward this position, that there were working pressures on the piston, divided by the ratio of the crank to the radius of the wheel, acting alternately on the two sides of the engine, and that these tended to produce sinuous motion. This, in Mr. Bramwell's view of the case, was an error; for when two wheels were keyed fast upon a shaft, of such strength as not to yield appreciably under torsion, there could be no difference of pressure (of this kind) between the two sides of the engine; and that was true, wholly irrespective of the number of cylinders, or the places where they were put. In order to show this he would refer to diagrams, Figs. 1, 2, and 3 (p. 86), for the elementary character of which he apologised. He had supposed, for convenience, as the Author had done, that the cylinder, one wheel, and the bearing were infinitely thin, so that they might all be considered as lying in one plane, and therefore there would be no occasion to take into account the places where the pressures bore upon the shaft. Fig. 1 assumed a wheel 6 feet diameter, and a crank 1 foot in length, and that the piston in its forward stroke pressed with a force of 3 tons. The black arrows indicated the pressures due to the piston, and the dotted arrows the opposite pressures, or those due to the cylinder cover. It was clear if there were a pressure of 3 tons driving the piston to the right, the tendency to drive the crank shaft to the right was as 4 : 3, as the crank and the radius of the wheel together would be a length of 4, while the radius of the wheel would be only 3. But that was in part counteracted by the pressure of 3 tons tending to drive the cylinder and framing to the left hand, leaving a balance of 1 ton for the propelling pressure of the engine, or the pressure on the piston divided by the multiple that the radius of the driving-wheel was of the crank.

Fig. 1.

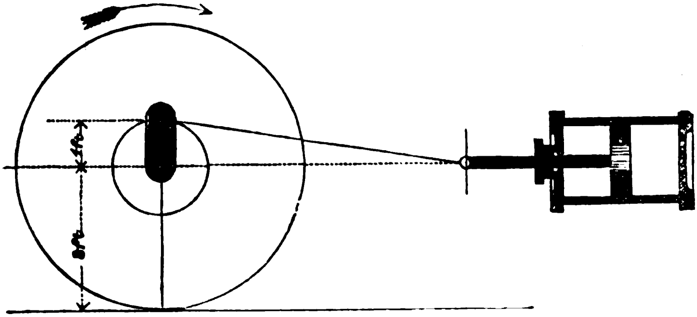


Fig. 2.

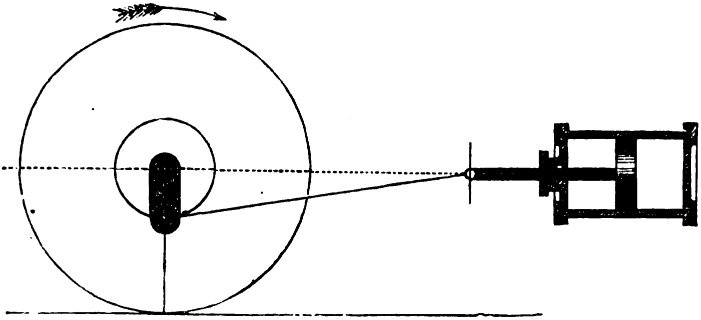
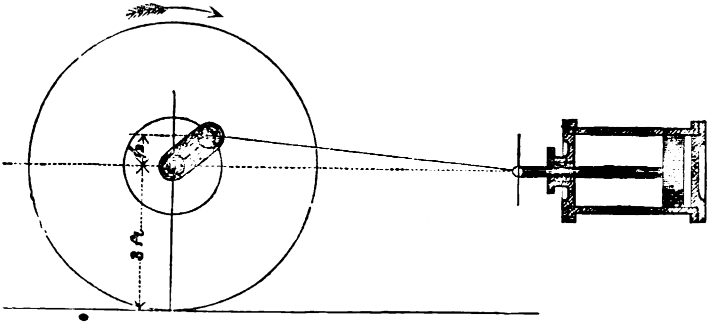


Fig. 3.



In Fig. 2 the piston was shown making the backward stroke. In this case the crank pin, instead of being above, was below the shaft. Therefore 3 tons pressure on the piston produced only 2 tons pressure upon the crank shaft; but 3 tons on the cylinder-cover produced 3 tons upon the frame and shaft, and the difference between 2 and 3, was the 1 ton for the driving pressure. In Fig. 3, the piston was shown as making its forward stroke with the crank at 30° from the horizontal. Following out the reasoning used when alluding to Fig. 1, it would be seen that the pressure now tending to propel the engine was only ½ ton; therefore it was clear the unbalanced pressure upon a bearing at any time was that due to the force driving the engine by that particular bearing, and that it could be nothing else.

Having, he thought, established that point, he would refer to a diagram (Fig. 4, p. 88), which, in order to test the principle, was illustrative of an extreme case; an engine, being assumed with one (the shaded) wheel only, and one cylinder, the piston being supposed to be in the act of making a forward stroke. The result of that would be to put a pressure of 3 tons upon the crank pin to the right,[1] driving the crank in that direction, but it would be reduced by the pressure from the cylinder-cover. Taking an imaginary line from the crank pin to the driving-wheel, and another through the centre of the shaft from the bearing to the centre of the wheel, then as the piston put on a pressure of 4 tons in the right-hand direction, at the point where these two lines crossed, this was balanced at that point by an equal pressure obtained from the cylinder-cover acting in the left-hand direction; and it would be seen, by tracing the two imaginary lines to the parts where they touched the driving-wheel, that the piston-pressure resulted in an effort to turn the wheel upon the rail, with a pressure to the left-hand of 1 ton (which might be called the abutment pressure), while the cylinder-cover put a pressure of 1 ton to the right-hand on the bearing close to the wheel, which was, in truth, the driving-pressure. Such an arrangement of one wheel would no doubt tend to produce sinuous motion, with a force proportioned to the distance of that wheel from the centre of gravity of the engine. But if the other wheel were taken into consideration, as being fixed on the shaft, then it would be seen that an engine which was capable of producing 1 ton of tractive force, must distribute it over the two bearings, and that there would therefore be ½ ton on each bearing; though the engine were driven by one cylinder, it was manifest it could not put a pressure upon one side of that engine, which was not equalled by that on the other side at the same moment. He trusted that he had made it apparent, that there could not possibly arise any sinuous motion from the driving pressures. If not true, then he would ask what would happen. Take the case of a paddle-steamer,

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[1] Mr. Bramwell wished to correct an error in the diagram (Fig. 4), viz.—the bearing on the right hand, instead of being drawn close to the crank, was shown away from it, and it had been put in such a position that unhappily the imaginary line indicating the transmission of the force from the crank-pin to the point where the driving-wheel touched the rail, appeared to cross it. He would request the meeting therefore to dismiss from their minds the position of the bearing, and suppose it to be in the plane of the cylinder.

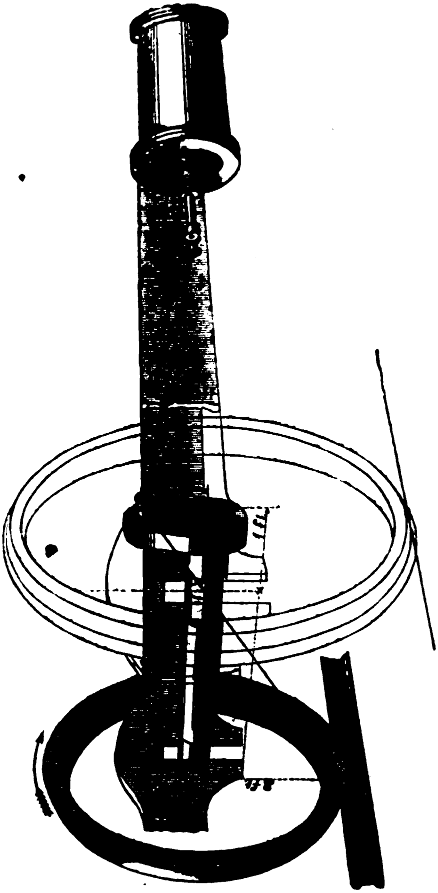
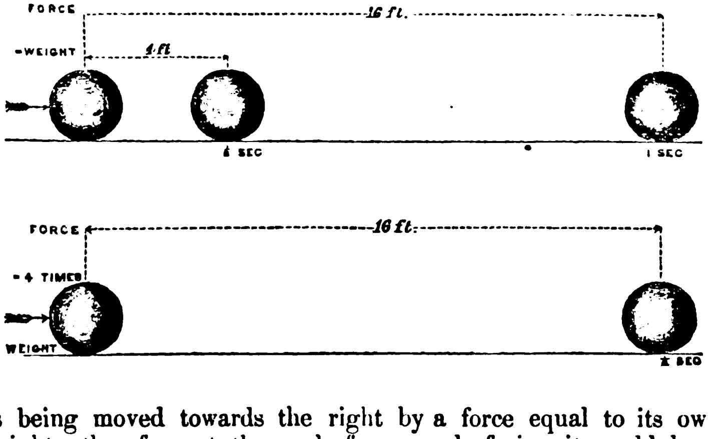


Fig. 4.

with a pair of wheels, and, as had occurred in his own practice, with the driving-engine on one side. Now, if the position of the cylinder in relation to the wheels it worked, whether those of a locomotive, or the paddles of a steam-boat, had anything to do with the amount of the driving-pressure on either side, that vessel ought to have carried helm on the side nearest to which the engine was. Again, in the case of a screw not fully immersed, and therefore producing a sideway pressure upon the bearing, such pressure ought to be greater, or less, according as the engines were placed aft, or nearly midships. Now Engineers knew, that no such result could happen in the case of the paddle-wheel, or of the screw, and he trusted his observations would lead to the conviction, that it was equally impossible for it to happen in the case of a locomotive. With respect to the disturbances arising from the momentum of the parts, no doubt there was such disturbance, but he could not help thinking that the Author had given it an undue importance, and that he had been led to do so by a neglect of this fact, that though the force of the parts in motion increased as the speed got higher, the times through which they acted decreased. The space through which these forces were capable of moving an engine must be equal for all speeds. Referring to another elementary diagram (Fig. 5), in the upper portion a ball was shown, which was assumed as being moved towards the right by a force equal to its own weight; therefore at the end of a second of time it would have moved through 16 feet, and in half a second it would have moved through 4 feet. In the lower part of the diagram a ball was shown which was assumed to be impelled by a force of four times its own weight. The result would be, that in half a second it would be moved four times as far as the 4 feet motion of the other ball, or 16 feet.

Fig. 5.

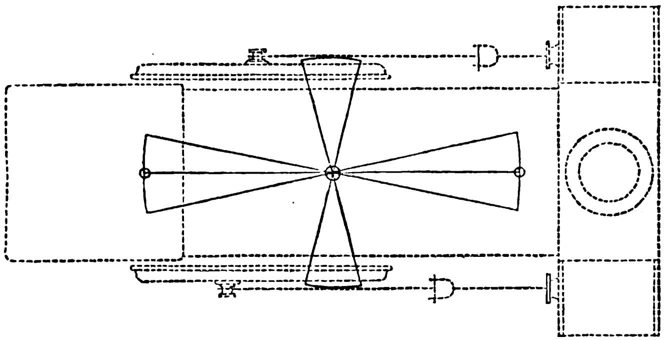


The consideration of this diagram (Fig. 5) showed, that if there were two forces, one of which was four times as great as the other, but acted for only half its time, this greater force would produce the same amount of motion as the first force. He did not say, however, the terminal velocities of the balls would be the same in the two cases, as no doubt, in the instances cited, the ball impelled by the greater force through the same distance would have a terminal velocity equal to twice that of the other. Applying these considerations to the question under discussion, if a locomotive had a velocity of one mile an hour, the force due to the momentum of the parts might be called 'one,' and the time during which it acted also 'one.' If the velocity were increased to 2 miles, the force would be increased as the square of the velocity (or 4), but it would only act for half the time. Similarly, if the velocity were increased to 10 miles, the force would be increased 100 times, but would only act for a tenth part of the time. Thus it would be seen, that whatever the speed of the engine, the distance through which the forces moved it must be the same for all velocities. The next point to which he wished to direct attention was the distance which the forces alluded to by the Author ought to move such an engine as he had described. Assuming, as the Author had done, the weights of the moving parts belonging to each cylinder to be 492 lbs., or in round numbers 500 lbs., and that 300 revolutions per minute were made, giving 63 miles per hour, or sufficient to fulfil all the conditions of a railway, then 500 lbs. and 300 revolutions per minute, at a radius of 1 foot, which was the length of the crank of the engine under consideration, gave, in round numbers, a maximum alternately of momentum and inertia of about thirty times the 500 lbs.

Therefore, each set of moving parts would give a pressure of 15,000 lbs. at the velocity he had stated. He thought it was in accordance with the Author's diagram to say, that the forces could not be taken as being of more value than was equal to their maximum through two-thirds of the whole revolution; and as 300 revolutions per minute had been assumed, which gave $\frac{1}{5}$th of a second for a revolution, it followed that the force of the moving part—viz., the 15,000 lbs.—could only act through $\frac{2}{3}$ of $\frac{1}{5}$ second, or $\frac{2}{15}$ths of a second. But it must be borne in mind, that even of this time, short as it was, only the latter half could be employed in producing motion, because it was clear the first half must be occupied by destroying the motion left by the immediately preceding impulse in a contrary direction, and that, therefore, in effect $\frac{1}{15}$th of a second was the time during which the momentum of the parts would operate to produce motion.

Having ascertained the time, the next point for consideration was the distance of the force from the centre line of the engine, for which purpose the weight of the engine must be taken into account, and a position be fixed for the centre of gyration of that weight. Diagram Fig. 6 was prepared to illustrate these points. He had assumed the centre of the cylinder, *i. e.*, the centre of the moving parts, to be 3 feet from the centre line of

Fig. 6.



the engine; that the engine weighed 60,000 lbs., or from 27 tons to 28 tons; that the weight was uniformly distributed over a length of about only 16 feet, giving the centre of gyration at 4 feet 6 inches on each side of the centre of the length. These proportions would reduce the 15,000 lbs. force of the moving parts to 10,000 lbs. when applied in the centre of gyration; and as this 10,000 lbs. would be equal to only $\frac{1}{6}$th of the whole weight of the engine, the effect would clearly be to move the engine only $\frac{1}{6}$th part of the distance through which it would be moved by the action of gravity operating for the same time. As this force would act for the $\frac{1}{15}$th of a second, and as the distances moved through were as the squares of the times, it would follow that the space in this instance would be only

$$\frac{1}{6} \text{ of } \sqrt{\frac{1}{15}} = \frac{1}{6} \text{ of } \frac{1}{225} = \frac{1}{1350},$$

and the $\frac{1}{1350}$th part of 16 feet, through which a body would fall in a second of time, was equal to about $\frac{14}{100}$ths of an inch. That being so, he trusted he had shown, that with a locomotive, the crank shaft of which was making 300 revolutions a minute, with a crank 1 foot in length, the moving parts of each engine weighing 500 lbs., and the weight of the locomotive being from 27 tons to 28 tons, there would be an amount of motion equal to only $\frac{14}{100}$ths of an inch; and it must be remembered, that while this would be the extent of each motion, the number of such motions, as they occurred at each revolution of the crank shaft, could not increase for a given distance travelled over, although from the greater number of revolutions per minute when the velocity was high, there would be a greater number of movements in a given time.

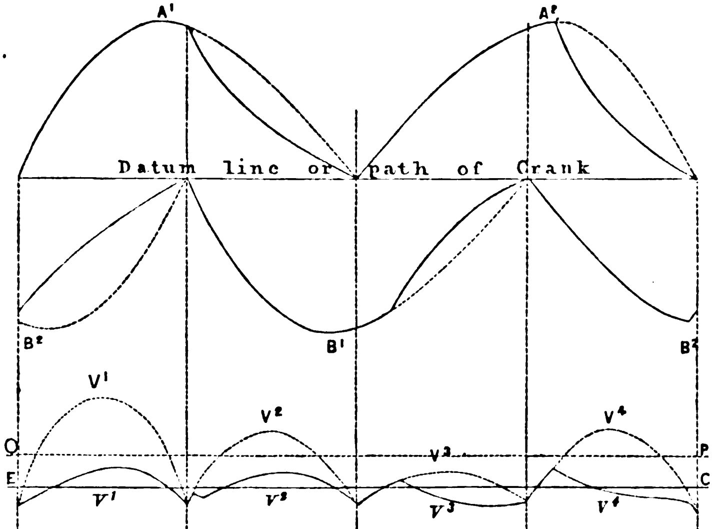
If these conclusions were correct, he thought it must be admitted, that the disturbance from the momentum of the parts was not so great as the Author imagined, and that the corrections proposed would make theory accord with practice. But even if these disturbances were so grave, then Mr. Bramwell would not seek a remedy by the construction of single-cylinder engines, to which there were great practical objections, while there were many better contrivances. There was the plan introduced by Mr. Bodmer, as early as the year 1834, of having two pistons in one cylinder, with the piston-rods issuing at opposite ends of the cylinder, and provided with suitable connecting-rods to the crank shaft. In 1841 Mr. Bodmer modified this plan, by having the two piston-rods to issue at one end of the cylinder, the one rod being made hollow to allow of the passage of the other. An engine of that kind he saw at work many years ago. Further, there was the 'Duplex' engine in the International Exhibition of 1862; also drawings by French Engineers, who proposed to employ four cylinders, two for giving a forward, and the others an aft motion. To his mind any one of these plans was superior to that which had been proposed by the Author. Supposing, however, a single-cylinder engine were to be used, he believed it would not be impossible to scheme an implement to enable the driver to start the engine. He had introduced into some heavy reciprocating machinery, a starting screw, which worked the machine up to the time when it was in a position to move without such assistance, and then this starting screw was simply thrown out of gear, by the mere act of the machine; but he hoped no one would ever be called upon to devise a similar plan to be employed upon locomotive engines.

Mr. J. Scott Russell said, although he had pursued a somewhat different mode of investigation to that adopted by Mr. Bramwell, yet it was curious that he should have arrived at almost identical conclusions, but for another size of engine; that was to say, taking the forces exactly as the Author had done, he found the total lateral translation in the mass of an engine by those forces would be in one case $\frac{1}{5}$th of an inch, and in another $\frac{1}{10}$th of an inch. He considered the valuable part of this Paper was the careful analysis which had been made of the forces as actually measured from the diagrams of Mr. D. K. Clark's observations, and the manner in which the various effects were recorded; all of which must be regarded as tending to eliminate the effects produced by the momentum of the parts. At all events, as he understood the matter, the diagrams truly represented the resolved transverse forces tending to displace the engine, horizontally, off the rails;

and to those, therefore, as the results of an investigation, which he had every reason to believe had been carefully carried out, he would apply himself. As far as he had followed this investigation, the practical effect of these disturbing forces would be this:—That if the engine wheels had no flanges, and the engine was going forward at the velocities stated, on a perfectly smooth surface, it would perform this vibratory oscillation, first on one side and then on the other. That being so, and taking the analyses, as given by the Author, of the times during which those forces acted at a speed of 35 miles an hour, he observed that each of those was acting during about $\frac{4}{16}$ths of a revolution, and as at this velocity a revolution was made twice in a second, it followed that each of the diagrams represented forces acting during the $\frac{1}{8}$th part of a second. The effect of that, compared with the effect of gravity, gave 3 inches as the total displacement which would take place, supposing those forces to act during an instant of time. In the next place, those forces were, as nearly as he could make it, the $\frac{1}{15}$th part of the mass which they moved; and it followed therefore that the lateral translation produced by the force in one of the diagrams was $\frac{1}{5}$th part of an inch to the right or to the left, as a maximum when the force was uniform. Taking the diagram as composed of two straight lines, one-half this amount, or the $\frac{1}{10}$th part of an inch, would represent the horizontal translation on either side. It appeared to him, that the inference to be drawn from this inquiry, as regarded the light to be thrown by theory upon a practical question, was that it was most desirable a theoretical investigation of this kind should have put in a visible form a series of tendencies, which were very small, but which certainly existed, and that every practical man should know those tendencies, and where they lay. The Author had, in his opinion, done good service in bringing forward the subject so plainly and so clearly, for when it was known where a bad tendency existed, however slight it might be, practical precautions could be taken to prevent its increasing and to diminish it. But it seemed to him that the subject should have been carried further, so as to embrace the measure of the effects of those tendencies; for it was not worth the trouble of inventing cures for tendencies, until the strict and rigid measures of the effects which those tendencies produced had been ascertained. If the Author would do this, before the Paper was printed, for the actual engine of which he had all the measures, then the communication would be more complete, and by that means he believed theory and practice would be thoroughly reconciled. In the early days of railways comparatively little attention was paid to the perfect balancing of the revolving and reciprocating masses in the locomotive engine; but now that this was done, railway travellers were not conscious of those serious jolts in every revolution, which the appearance of the diagrams would lead them to apprehend. The Paper gave rise to one valuable suggestion, the importance of allowing considerable play between the flanges of the engine and the rails. These should not fit each other too closely; and it appeared that, in a good engine, a lateral free play of more than $\frac{1}{5}$th of an inch on each side of the centre line did take place, and considerably more must be allowed. It was much more comfortable to stand on the foot-plate of an engine when going round a curve, than when running on a perfectly straight line, as in the latter case there was a series of oscillations, and all the road did on the curve was to guide that side, and prevent the engine going towards the other side. It was important that attempts should not be made to remedy small evil tendencies, by serious and formidable measures. He thought, if Mr. Bramwell and he were right in their measures of the horizontal translation, that this amount of oscillation should not lead to the conversion of the double-cylinder engine into a single-cylinder engine, with all the mechanical inconveniences which attached to the latter. He was sure that no engine-driver, who had limped home with only one cylinder at work, or who had one or two inclines to surmount, would wish to 'improve' the double-cylinder engine by making it a single-cylinder engine. He was glad that justice had been done to Mr. Bodmer's plan of balancing the engine. He had noticed substantially the same plan as Mr. Bodmer's in an Austrian engine in the International Exhibition of 1862, yet if it turned out that the measures of the effects given were near the truth, he thought no one would recommend a considerable deviation from the established form, to get rid of tendencies, the measure of whose effects was really so small.

Mr. COWPER could not agree that there was any necessity for having resort to a kind of Cyclops engine with one cylinder, in order to remedy the defects mentioned, in the balancing of locomotive engines. Indeed it hardly seemed to require an argument to prove, that it was unwise so to construct an engine, as to produce the greatest possible amount of snatching at the drag chains, or irregularity in the tractive power; to say nothing of putting a crank with twice the ordinary strain upon it, in the centre of the axle, where it was weakest, and where in fact there was no room for it to go round under the boiler. The result of concentrating the whole power in one cylinder would be, that in place of a somewhat distributed rotative force, there would be two portions of each revolution during which the engine would not even have power enough to drive itself, and must therefore be propelled by the pressure of the train behind. This would be a great evil; but a still more formidable objection would arise from the power being excessive at two other portions of each revolution, nearly twice what it ever was, with an ordinary engine having two cylinders. Practical locomotive engineers knew that the weight on the driving wheels had to be adjusted so as to give sufficient adhesion to the rails; and that often this weight was quite as much as it could be made with safety. Now if one cylinder only were used, nearly double this weight would have to be applied. In ordinary heavy engines, and particularly those for luggage trains, it was generally absolutely necessary to couple at least two pairs of wheels, in order to obtain sufficient adhesion; and with a single-cylinder engine, of the same power, it would be impossible to get the extra adhesion required to make the wheels 'hold' the rails. It was unnecessary further to allude to the starting of the train, as that was so great and self-evident a difficulty, that any proposition for a single-cylinder engine was incomplete, without the means being defined by which the engine was to be started. With regard to the plus and minus pressure caused by the momentum of those parts of an engine which moved horizontally, in a straight line, backwards and forwards, he was well aware that it was a matter worthy of serious consideration; for although it had received some attention, much more was required, in the way of direct trials of improvements, and alterations in the weights and position of the parts, before the best result could be attained. He had designed, many years ago, an arrangement for balancing a quick-working machine, moving a weight by means of a crank. A second crank was placed precisely opposite to the first, to move another similar weight, so that the machine was completely balanced. Mr. Heaton, of Birmingham, had proposed the same plan for a locomotive, and had constructed guides under the foot-plate of an engine, on the London and Birmingham Railway, and placed an outside crank on the axle to work a dummy weight in the guides, so as exactly to imitate the piston, &c., the cranks being opposite. This made the engine run very steadily indeed, and was so far successful, though the complication was of course objected to. Recently the doffers of carding engines had been balanced with second cranks and dummy weights, with great advantage to their quick and smooth working. With regard to the effect produced by the reciprocating parts of an engine when left unbalanced, he could not agree that the $\frac{1}{5}$th of an inch was practically anything like the real measure of the sinuous motion of most engines; indeed, from his own observation, he felt convinced that the motion was much more like 2 inches, at the ends of the frame, even with a good road, and more if the road were bad. Nor did he think that a small measure of motion expressed the evil in its true form, as it was, or might be at any instant that the flange was in contact with the rail, a question of the amount of force that was exerted against the rail, tending to bend the rail or break the chair. He believed for this reason that high speeds were far more dangerous, when the ballast was frozen hard, than when the road was in an ordinary condition. The plus and minus pressure under ordinary circumstances was upwards of 8,000 lbs. for each cylinder. With respect to the uniformity of the rotative power, irrespective of the plus and minus pressure, it would be seen from the diagrams, that one cylinder with full steam was the most irregular, next came two cylinders at right angles with full steam, whilst the most uniform rotative power was obtained by using two cylinders, and cutting off the steam at a little before, and a little after half-stroke. The advantage of cutting off steam at half-stroke had been first pointed out, in 1849, by the Author of a Paper read at the Society of Arts. Fig. 7 showed the variation in the rotative power obtained by using full steam throughout the stroke in two cylinders, having cranks at right angles, and also the variation when cutting off at certain definite points. The full lines A^1, A^2, represented the rotative power obtained from the two strokes of one cylinder, as developed on the path of the crank, whilst the full lines B^1, B^2, represented the power obtained from the other cylinder, also developed on the path of the crank, when using full steam in both cylinders. The dotted lines V^1, V^2, V^3, V^4, showed

Fig. 7.



the combined rotative power of the two cylinders, and a variation from the average line OP of 31 per cent. It should be stated that, if expansion were carried to any extent in each of the cylinders separately, this variation would be much greater. The full lines A^1, A^2, and B^1, B^2, showed the rotative power when cutting off at the points indicated, and the lines v^1, v^2, v^3, v^4, showed the combined rotative power of the two cylinders, working as just stated, giving a variation from the average line E C of only 14 per cent., which in practice amounted to perfect uniformity in effect. The length of the connecting rod had been taken into account in Fig. 7. It should also be noticed, that when using full steam, the variations in power were not only large, but long continued; for instance, in the first quarter of the revolution, the power was greatly in excess of the average, whereas in the third quarter it was greatly below the average. When cutting off at the particular points before noticed, each quarter had nearly the same power.

In conclusion, he would beg once more to urge locomotive engine builders, in common with marine engineers, to use steam-jackets both to the cylinders and the cylinder covers, as he felt it was an improvement that had been far too long neglected. He was bound, however, to say, that some marine engineers were now beginning to appreciate steam-jacketing, though the Government neglected it still.

Mr. **Phipps** said, with regard to the supposed advantage of one cylinder over two cylinders, he was willing to concede, that as all the reciprocating parts would be situated in the middle of the single-cylinder engine, it would be free from the sinuous motion, which in the double-cylinder engine was occasioned by the resistance to the change of velocity in those parts, acting on the mass of the engine, with a determinate leverage. As regarded tractive power, however, he could not agree that there would be anything like the same equality of pull in the single-cylinder as in the double-cylinder engine. If the tractive power of the two classes of engines were examined, simply with relation to the pressure of steam on the pistons, and the effective leverages of the cranks, it was easy to show, that whilst the maximum and minimum rotatory power of the double-cylinder engine varied in each quarter revolution nearly in the proportion of 14 to 10, in the single-cylinder the variation was as much as 20 to 0. That was, for the double-cylinder, the area of each being 6, when the cranks were at A and C (Fig. 8, page 98), if the power were taken as 10, at B and D, it would be as 14 nearly; while for the single cylinder, whose area was 2, when the crank was at A, the power would be as 0, whilst at B it would be as 20. As, however, the Author in his Paper stated, that in estimating the rotatory power of the engine, it was necessary to incorporate with the pressure of steam on the pistons, the effect of the inertia of the reciprocating parts, it could be shown that, in the cases illustrated by these figures, the inertia was totally inoperative, and therefore that the proportionate variation of power remained unaltered. For example, whenever the cranks were at any of the positions A, C, E, or F (Fig. 8), the reciprocating parts attached to them were undergoing neither acceleration nor retardation, and could not therefore be either absorbing power from the steam, or giving out power. Also when the cranks were at B and D (Fig. 8), the parts attached to B were being accelerated, precisely in the same degree that those at D were retarded, and hence the original power of the steam was not interfered with. These results were calculated on the supposition of full steam being used throughout the stroke. If cut off at half-stroke, the friction connected with the crank at D (Fig 8) would only have upon it $\frac{35}{60}$ths of the pressure on the other piston connected with B, whence the total rotative power would then be as 11·08 in the position of B and D, compared with 10, as before, when at A and C.

Fig. 8.

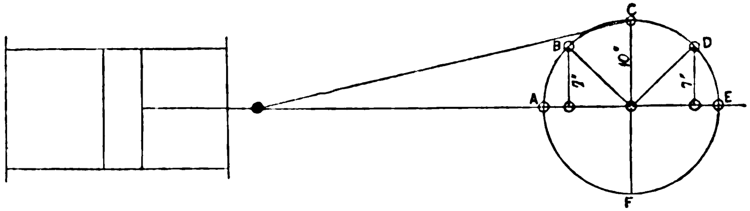
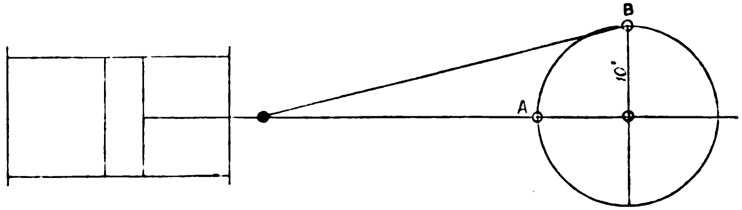


Fig. 9.



Mr. Sinclair said, he had had considerable experience in the practical working of the locomotive engine, and was surprised to hear that the sinuosities of its motion had been reduced, by calculation, to $\frac{1}{5}$th or $\frac{1}{10}$th of an inch. In all his experiments with these machines, he had never found one whose irregularity of motion was not much greater than anything which had yet been stated in the course of this discussion. He believed it had been the universal practice to apply weights to the wheels, for the purpose of balancing the irregularity of motion, and that by that means the irregularity had been reduced to a minimum: but he had never met with one whose minimum amount of irregularity was not greater than had been mentioned. These balance weights might be applied until the irregularity was reduced to a minimum, but beyond a certain amount the more the weight was increased the greater would become the motion. He had always entertained the belief, that irregularity was due to the varying position of the several reciprocating parts of the engine; that beyond a certain point it was next to impossible to alleviate it; and that however perfectly the engines might be designed, so long as there were two cylinders, a certain amount of sinuosity or oscillation must result; but that the measure of it, according to his experience, was considerably greater than had been pointed out. Then, unfortunately, any defect in the original design was aggravated as the engine got out of order, and whenever the way upon which it travelled was not in a good state; and neither could be assumed to be so perfect, under all circumstances, as to prevent this increased injurious effect taking place. He believed that if a single-cylinder engine could be got to go at all, it would neutralize, to a great extent, these sinuosities and irregularities. He had for many years had that notion; and a long time ago he took an engine, which had become deteriorated by long use as a ballast engine, and which, at a slow speed of 15 miles an hour, was very uncomfortable to travel upon, and although he did not actually convert it into a single-cylinder engine, yet the two cranks were placed in the same direction, so that for all practical purposes it was a single-cylinder engine. That engine—when it could be got to go—that was when the difficulty of getting over the centre was overcome—travelled 60 miles or 70 miles an hour with perfect steadiness. Therefore he was led to think, if that inconvenience could be overcome, a simple and a steady engine might be obtained. Although he had applied himself assiduously to the subject, he regretted to say that both his ingenuity and patience had been at fault, for he had not yet been able so to arrange such an engine as to give facility for starting or reversing, without which it was of course useless for practical purposes.

Mr. **Gravatt** remembered that twenty-five years ago, when driving wheels of 10 feet in diameter were in use, he investigated this question. The result then arrived at was, that if there were no torsion, there would be no sinuosity. The whole thing depended upon the torsion of the crank shaft. If the shaft was indefinitely stiff, and the wheels were all going at the same speed, there could be no sinuosity.

Mr. **Kershaw** thought there could be no question, that an action of a side character took place in an engine, but not to so dangerous an extent as the diagrams indicated. The speed at which the whole of the parts ran had a tendency, he believed, to counteract any evil effect, and there was no reason to apprehend danger from diagrams of the nature of those exhibited. The single-cylinder engine appeared to be considered as wholly impracticable, therefore it was not necessary to enter upon that question.

Mr. MOLESWORTH said, the theory of the disturbing forces had been so fully gone into, that there was little left to add upon that point. Although agreeing, to a certain extent, with the remarks which had been made on that subject, he yet held the opinion that, practically, the measure of motion very greatly exceeded what was indicated by the theory which had been propounded. He ascribed the discrepancy between theory and practice to the fact, that the theory was based upon the supposition that the wheels were without flanges, whereas, in his opinion, the flange was a very important element in the question. When the direction of the course of an engine at a high velocity was suddenly altered by any disturbing force, the momentum of the engine brought the flanges into violent contact with the rails, and the elasticity of the rails caused the engine to rebound, or rather glance off, against the opposite rails. When the rebound happened to be simultaneous with a disturbing force acting in the same direction, the maximum oscillation was caused; but the rebound was in some degree neutralized, when the disturbing force acted simultaneously in the opposite direction. In support of this view it was adduced, that the oscillations of an engine were not coincident with its pulsations, as they would be in the theoretical case of an engine without flanges; but that they were very irregular, sometimes extending over a period of eight or ten pulsations.

A single-cylinder engine he considered to be impracticable. Even if means could be devised for starting the train under ordinary circumstances, that was not the only difficulty; as it would be much increased in frosty weather, a drawback which could only be fully appreciated by one who had driven an engine, and had experienced the difficulty of starting a heavy train in slippery weather. He presumed that the apparatus for starting would be worked by hand, and thrown into gear so as to move the engine off its dead centre; after which it would be thrown out of gear, and the steam would carry on the stroke. When the rails were slippery, the wheels, if moved off their dead centre, would rotate a few times without biting, and would probably stop on one of the dead centres again, as the steam would have the least power at those points to make the wheel rotate; the hand apparatus would then have to be thrown into gear again, and the engine worked off its dead centre, probably with the same result as before.

Mr. VIGNOLES said it appeared to him, that the object the Author had in view was to ascertain how far the engine itself was at fault, and how far blame might be laid upon the permanent way. It had been satisfactorily demonstrated theoretically and practically, that the sinuous motion of the engine was but small, and that it was not so injurious as had been supposed; and he believed in the earlier experiments upon railways, it had been proved that, where the railway was in perfect order, the flange of the locomotive might be almost dispensed with. Therefore the remedy for the evils described must be found in the perfection of the permanent way. When the subject was first broached, he thought too much blame had been thrown upon the deficiencies of the permanent way, and too little assigned to the locomotive engine: but he now considered that, when the problem was the revolution of the engine upon a theoretically perfect line, and as the maximum amount of sinuosity was only one-fifth of an inch, if an accident arose, it must be from other causes than defects in the construction of a well-balanced modern locomotive, and that safety must be sought in the perfection of the road. So small a lateral deviation as the one-fifth of an inch might sometimes arise from the imperfection of a chair, and he would ask, why should chairs be used at all, since the most perfect way was also the simplest, and chairs were merely a complication and only uselessly increased the number of parts? Defects in the way comprised the want of perfect gauge, of perfect gradient, and of perfect smoothness of the whole of the parts. The perfection of gauge was of course insured by the transverse sleepers to keep the rails in place; the perfection of the vertical position of the rails by attention to the ballasting and by packing; while as regarded smoothness, the junction of the rails, by means of fish plates, enabled one even continuous line to be obtained, which was so important to the easy action of the engine travelling over it.

Mr. G. W. **Hemans**, without controverting the scientific inquiry into the action of the disturbing forces in the locomotive, and the measure of their results, would record his opinion, for what it was worth, that these sinuous movements were very serious. He had had occasion to observe the movements of engines on one line in particular, where a great proportion of the stock consisted of inside-cylinder engines, there being only six engines with outside cylinders, and he found that the sinuous motion with outside cylinders was greater than with inside cylinders,—so much so indeed as to be dangerous,—and the result of the investigation showed the movement to be much more than the one-fifth of an inch indicated as the limit in theory. He believed this irregularity arose from imperfection in the machinery; that there was a movement in the axles of the engine, which did actually bend and suffer some amount of torsion, which in outside-cylinder engines with light axles might be serious. If, as he thought was the case, outside-cylinder engines had more sinuous motion than those with inside cylinders, it was clear that the sinuous motion must arise from a want of proper balancing. The adoption of a single-cylinder engine, which was the remedy proposed by the Author, was not, in his opinion, one which would cure the defect, or remove one present source of safety. When an engine with two cylinders was partially disabled, it could be brought home with one cylinder working; whereas the single cylinder would take away that important chance of safety, and on that account would be objectionable.

Mr. G. P. **Bidder**,—Past President,—thought it desirable to come back to the essence of the Paper, which undertook theoretically to point out the sources of danger in engines, and to suggest a practical remedy; and here he would remark, that the observations, on which the investigation was based, were, in his opinion, as unpractical as the remedy proposed for overcoming the evils that had been described. The Author alluded to the fact, that the side pressure, arising from the position of the cranks, was a source of great increase of resistance; and confirmed that position, by reference to the effects of a very strong side wind upon the train. Now it had been satisfactorily established, that the resistance of a strong side wind was not due to side pressure, but to end pressure; and that strong side winds became diagonal, when combined with the speed of the train, and would thus be distributed partially over the ends of all the carriages; whilst a direct end wind operated on the end of one carriage only. It frequently happened, especially in regard to railways, that remedies designed to overcome one evil, themselves introduced other sources of danger. The Author had suggested a single-cylinder engine; but that, he thought, had already been satisfactorily disposed of as a most unpractical idea. If it were desired to get rid of this sinuous action, or tendency to sinuous action, it could be done with two cylinders, by putting both the cranks in the same position, instead of at right angles to each other; and that would be a more practical method than the one proposed. This had been accomplished by the late Mr. Robert Stephenson, in a three-cylinder engine, having one large cylinder in the middle and two smaller ones at the sides. That engine worked with remarkable steadiness, but it was costly, and that, together with the complication of the parts, prevented its adoption. In 1836 Mr. Weallens, of Newcastle-on-Tyne, brought out an engine with four cylinders; and it was a curious fact that there was an engine upon that plan in the late International Exhibition of 1862. But although by the use of a single-cylinder engine, or a double-cylinder engine with the cranks moving together, the sinuosity might be avoided, another element of danger was introduced, inasmuch as there must be a varying pressure between the back and the forward motion of the engine, which would produce a jolting action that was likely to give rise to accidents from the breaking of the connections of the train. Therefore, practically, all these suggestions failed, and he thought they would hardly have occurred to any one conversant with, or experienced in, the working of railways. He concurred in a great measure in the remarks which had been made, as to the extent to which the oscillation of the engine was occasioned by the varying operations of the steam in the cylinders. But there was this fault in the deductions, that the whole mass of the engine had been taken into account. If that were done, there could not be a side motion without causing the wheels to grind literally upon the rails; and as the friction was one-sixth of the weight, it would be found, if the whole mass of the engine was taken, that the pressures given by the Author could produce no sinuous action at all. But the fact was, that part of the mass of the engine should be taken which was upon the springs, and this was much less than the whole; therefore the motion communicated to this portion of the bulk of the engine would be in excess of the results arrived at by Mr. Bramwell and Mr. Scott Russell. But even then the amount of oscillation which was known to exist would not be reached; and so long as there were wheels and cranks, and engines were put on railways with curves, so certainly would the element of oscillation be introduced. With a perfect road, and an engine perfectly adjusted, it was not in the power of man to place that engine perfectly straight upon that railway, and then, at once, the element of oscillation came into play. Besides, an engine that was put on the road perfect on one day would not be so on the following one. The eye failed to detect those defects in a railway which occasioned oscillation; and not only the eye, but no instruments could do it. Neither could those errors in the construction of the engine which occasioned oscillation be detected. If any one of the wheels were out of truth the one-hundredth part of an inch, that might occasion serious oscillation. There were no means of investigating the extent to which these defects prevailed, because they might be acting either together or in opposition to each other, and thus aid or retard the oscillation, or the tendency to oscillation, which the backward and forward pressure of the steam in the cylinder must occasion to the boiler and other parts connected with it. Therefore it was found in practice, that engines, more or less imperfect, ran at high velocity for a long period without accident; whilst a new engine, or, what was better, one which had run a few journeys, might be put upon as perfect a piece of road as man could make, and an accident might forthwith ensue. The investigation of this subject, so as to embrace all the elements which tended to affect the action of the engine, demanded very high mathematical powers, combined with great daily experience in the working of railways. If that combination could be brought about, data would be afforded of great practical value to locomotive managers, and to those who were so much, and so painfully, interested in the results of railway accidents.

Mr. REYNOLDS thought one point had been overlooked in considering these disturbing forces, and that that was the only one of practical importance, because, though it must be admitted that many imperfect engines were running, still the ordinary knowledge of engineers, if properly applied, was sufficient to enable them to neutralize the evils arising from the sources of disturbance which had been discussed. The effect of the inertia of the pistons, &c., was well known; but he could not conceive how the combined action of the two sets of parts making strokes alternating with each other in the usual way, and having, therefore, in the course of each revolution, four periods of acceleration and of retardation at (neglecting the influence of length of connecting rod) equal intervals, could possibly produce diagrams like those shown in Plate 2, Diagrams No. 5. It surely must be more like that exhibited in Fig. 7, page 34. It was only fair to say, that in Mr. D. K. Clark's treatise the question of sinuous motion arising from the inertia of the moving parts had been carefully, and as it appeared to him, accurately gone into. The effect of such inertia could be, and in practice frequently was, completely neutralized by balance weights in the wheels. It was true that if there was sufficient balance in the wheel to counteract the horizontal action of the piston, &c., a new tendency was introduced, which, however, at the speeds attained in practice, did not practically affect the motion of the engine. He meant that as the balancing weight must be greater than that necessary to counteract the centrifugal force of the revolving parts, a greater pressure was caused upon the rail at one period than another, and thereby a slight inequality in the wear of the wheel tires was in practice produced; but as the amount of unequal pressure was not sufficient to lift the wheel from the rail, the horizontal action of the balance weights alone came into operation, so far as regarded the motion of the engine. As had been previously stated, he believed the amount of displacement of engines was generally much greater than had been calculated by some of the speakers; but he thought it might be accounted for, by considering that the engine had as much tendency to turn itself round the driving axle, as to turn the axle in its bearings. If this tendency was uniform, it would merely amount to a transference of weight from the leading to the driving and trailing axles, and if it was centralized, as in Mr. Robert Stephenson's three-cylinder engine, it would not induce, or affect, lateral motion, but in practice the action took place alternately at opposite corners of the engine, and the amount of the tendency might be taken for the present purpose to be represented by the upward pressure of the slide blocks upon the slide bars. The "White Horse of Kent" had been referred to. A number of engines of this class, which had come under his observation, had 15 inch cylinders, 2 feet stroke, and 6 feet driving wheels, and the connecting rods were about 5⅓ times the length of the crank. Speaking from memory, the usual weight was about 21 tons, disposed thus:—leading wheels 5½ tons, driving wheels 9 tons, and trailing wheels 6½ tons. Hence, if the engine had 100 lbs. per square inch on the pistons, the total pressure on each piston would be 17,600 lbs., and this divided by 5⅓ would give something like 1½ ton lift on the slide bars; and as the whole weight on the rails at the leading wheels was only 5½ tons, of which the wheels and axle would weigh more than ½ ton, leaving only 5 tons, or 2½ tons upon each leading spring, and as these springs were only 4 feet between centres, whilst the slide bars were 6 feet 1 inch between centres, it was easy to understand how considerable motion might be produced. He once had occasion to make a number of small engines, with 14 inch cylinders, 18 inches stroke, and 4 feet wheels, only 6 feet between the extreme centres. The leading wheels were coupled to the drivers, by return rods inside the connecting rods, and the distance between the centres of the cylinders was 6 feet 4½ inches. The connecting rods were 8 times the length of the crank, and though there was not the usual rigid coupling between the engine and tender, yet (the wheels being carefully balanced) these engines were practically steady when lightly loaded, at any speed which the length of line at his command admitted. But when heavily loaded, or working up severe inclines, the way in which they, as it were, worked their shoulders was very conspicuous. It was clear that this action would be more considerable in proportion as the cylinders were farther from the centre of the engine. In modern inside-cylinder engines, with the ordinary loads, it was not generally visible, except in the case of goods engines, which were generally well loaded, and had the additional disadvantage of inclined cylinders, which concentrated the action referred to in one of the strokes, instead of dividing it equally between the two; and no balance weights could modify the effect of this tendency. Even in the duplex arrangement, where the balance, so far as the parts in motion were concerned, was practically perfect, he believed that, when heavily loaded, the action to which he had directed attention would be traceable, in spite of the excellent disposition of the weight upon the wheels. He thought the operation of balance weights was in some cases less satisfactory than it might be, because they were very commonly wrongly placed. He had seen some few inside-cylinder engines correctly balanced, having upon each wheel two balance weights;

the amount due to each set of parts (crank, piston, &c.) being divided between the two wheels in amounts varying inversely with the distance from the crank. Thus there would be a large and a small weight upon each wheel, and the same effect was sometimes obtained by the use of a single weight in each wheel of such amount, and in such intermediate position, as would be equivalent to the two weights described; but he never yet saw an outside-cylinder engine correctly balanced. It was clear that a single weight in each wheel, radially opposite the crank, could not be right, unless the planes of motion of the piston, &c., and of the wheel coincided, and it also seemed to him that for inside-cylinder engines, the position of single weights in each wheel must be at an angle with each other smaller than a right angle; and the amount of such weight would be somewhat less than would be required if the weight revolved and the piston moved in the same plane. For outside-cylinder engines the two weights must be at an angle greater than a right angle, and the amount must be greater than that due to the action of the piston and balance weight in the same plane.

Mr. W. NAYLOR could only agree with the Author as to the bare fact that there were sinuous and oscillatory motions in locomotive engines, but he differed entirely as to the cause. He was prepared to show, that sinuous and oscillatory motions took place in all railway vehicles, as well as in locomotive engines, and that it always must do so. He was well aware that this motion might be greater in one class of vehicle than in another, and that one class was more destructive to the permanent way than another which had more oscillation, and he could give many instances of parts of trains running off the line, when the engine and tender had not done so.

Mr. C. B. LANE observed, through the Secretary, that some of the results of the disturbing forces at which the Author had arrived, would be much greater in a broad gauge than in a narrow gauge engine; for the unbalanced reciprocating portions of the engine referred to in the Paper, which were estimated to weigh 495 lbs., and to the action of which was ascribed that sinuous motion of the locomotive on the rails that tended to burst the road, must, in the case of the broad gauge, as contrasted with the narrow gauge, act at the extremities of levers in the ratio to each other of 7 feet to 4·66 feet, and therefore produce a much greater amount of deleterious action in the former case than in the latter. As many of the points relating to the question of gauge had turned more upon commercial or financial considerations, it appeared important to notice this mechanical one.

Mr. MAKINSON, in reply upon the discussion, said Mr. Bramwell appeared to hold the opinion, that the steam pressures in the cylinders had no tendency to produce sinuous motion in the engine.

He thought the contrary was proved, simply by reference to the well-known proposition in dynamics, that in order that a body might move with a motion of translation only, the resultant of its impressed forces must act through its centre of gravity. With regard to the remark, that any oscillation in the engine, produced by the internal disturbing forces, would be the same at all velocities, two erroneous assumptions were made, when it was taken for granted that the time allowed for the oscillation varied inversely with the velocity of the engine, and that the disturbing force varied directly as the velocity. Now the Diagrams No. 8 (Plate 3), showed that at the velocity of 26 miles per hour, there was a tendency in the engine to make two oscillations in each revolution of the driving wheel, and that at the velocity of 52 miles per hour there was a tendency to one oscillation only in each revolution; so that the time allowed for an oscillation was the same whether the train was moving at 26 or at 52 miles per hour. The pressures shown in the diagrams, as tending to produce oscillation, were opposed by the friction of the wheel on the rail. The difference of these two pressures was the moving force producing transverse motion; and whether this friction were assumed at $\frac{1}{4}$th or only $\frac{1}{10}$th of the insistent load on the wheel, it would be seen from the diagrams, that the moving force increased somewhat more rapidly than the velocity. He must contend that the diagrams were quite sufficient to prove the incorrectness of Mr. Bramwell's conclusion; and although they had a special and not a general character, they were at all events suggestive of the conclusion, that engines travelling at high speed acquired a dangerous amplitude of oscillation.

Mr. Scott Russell, while accepting the accuracy of the numerical values assigned to the forces tending to give lateral motion or oscillation to the engine, regretted that attention had only been directed to those tendencies, and suggested that the Paper would have been more complete, if a measure had been given of the amount of the lateral motion. Mr. Russell had himself undertaken to supply this deficiency, and gave as the result of his calculation, that the lateral movement would be between $\frac{1}{10}$th and $\frac{1}{5}$th of an inch. Considering this as insignificant, and, in fact, hardly worth eliminating, the conclusion was arrived at by Mr. Russell, that the remedy, the single-cylinder engine, for so slight an evil, was worse than the disease. Had a three-cylinder engine, like that constructed by Mr. Stephenson some years ago, or a four-cylinder engine, like the 'duplex' in the late International Exhibition of 1862, been proposed, then Mr. Makinson could have recognized more force in the conclusion; but, so far from any complexity being introduced, the single-cylinder engine would be simpler in construction, and have fewer working parts than the present engine. He had wished to avoid the attempt to determine, theoretically, the lateral movement of the front end of an engine while running, but as it appeared to be desired that he should do so, he would apply to the case the same dynamical law as had already been employed in the course of the discussion, which was represented by $\frac{f}{2} T^2 = \int$, where f is the increment of velocity produced in 1 second by the moving force, T the time in seconds of the application of that force, and $\int$ the space in feet. Let W be the weight on the leading axle, n W the friction of the wheel on the rail, and let F represent the outward pressure on the rail generated by the engine; then F $- n$ W was the moving force, and $f = 32 \times \frac{(F - n W)}{W}$ and $\int = \frac{32 (F - n W)}{2 W} . T^2$. But when the front end of the engine had been thus moved through the space $\int$ by the moving force (F $- n$ W) it had acquired a certain velocity of lateral motion; so that when the moving force ceased, a further lateral motion $= \int$ would take place before a state of rest was attained. Therefore the whole lateral displacement would be $\int = \frac{32 (F - n W)}{W} T^2$. The utmost value of $\int$ which the play of the wheel would allow was $\frac{1}{4}$th of an inch, or $\frac{1}{48}$th of a foot. The friction n W would vary with the state of the rails from $\frac{4}{10}$ W to probably $\frac{1}{10}$ W. He was at liberty to assume the most greasy and slippery state of the rails, and therefore to take $n \text{ W} = \frac{1}{10}$ W. There was then obtained $\frac{1}{48} = 32\left(\frac{F}{W} - \frac{1}{10}\right)T^2$; and assigning the numerical values to F and W, the time T through which F must act to drive the flange of the wheel laterally $\frac{1}{4}$th of an inch, and into contact with the rail, would be arrived at. One of the diagrams (Fig. 8 B) showed that F attained a maximum value of nearly 2 tons; but supposing that F $= 1\frac{1}{2}$ ton only, and that W $=$ 5 tons, then

$$\frac{1}{48} = 32\left(\frac{1 \cdot 5}{5} - \frac{1}{10}\right)T^2 = \frac{64}{10}T^2;$$

$$\text{therefore } T^2 = \frac{10}{48 \times 64} = \frac{\cdot 21}{64^2}, \text{ and } T = \sqrt{\frac{\cdot 21}{64}} = \cdot 056,$$

or about the $\frac{1}{20}$th of a second.

Now in this same diagram, Fig. 8 B, each inch on what represented the rail line corresponded to about the $\frac{1}{200}$th part of a second; and it would be seen that there were 10 consecutive inches where the outward pressure exceeded the assumed value of F $= 1\frac{1}{2}$ ton. So that it might be proved, that even so well proportioned an engine as the "Great Britain," at 52 miles per hour, with a greasy state of the rails, would twice, in every revolution of the driving-wheel, move laterally ¼ of an inch and strike the rail with the wheel flanges. A blow, once originated, between the flange and rail, would, from their elasticity, entail a series of blows at regular intervals of time; and should any of this series coincide in time and direction with the constantly recurring impulses to transverse movement originated by the engine, a heavier blow between flange and rail would follow, and so on again and again. And just as a small pressure suddenly applied to extend a metal rod of however large a section, and applied isochronously with the vibrations of that rod, would ultimately create a force of tension great enough to rupture it, so was it conceivable, that the pressures shown on these diagrams, occurring simultaneously with the rebound of the wheel from the rail, might ultimately produce a lateral pressure large enough even to drive the flange of the leading wheel up the rail, and so cause the engine to leave the rails. The foregoing was not proposed as indicating all the series of movements which together determined the amount of oscillation of the engine. But he believed sufficient had been said to refute the attempt which had been made to prove that the internal disturbing forces of the ordinary two-cylinder locomotive could not give rise to oscillations of that magnitude and danger which, as a matter of constant observation, did occur in such engines at high speed.

It seemed to be considered, by Mr. Vignoles, that the present engine, so far as steadiness of motion was concerned, was practically perfect, and that all oscillation might be referred to defects in the permanent-way. Then he would ask, why travelling on a railway worked on the atmospheric principle was so decidedly superior, in ease and steadiness of motion, to travelling on a railway worked by the locomotive? The variations in the amount of tractive force of the locomotive engines of the present construction might be illustrated, and rendered more appreciable by the mind, by a consideration of the inequalities of permanent way, to which they were, in their effect on coupling-rods, and shaking and jarring of carriages and passengers, virtually, equal. Referring to diagram Fig. 5, it would be seen that at 26 miles per hour, while the crank pin moved through 30 inches, and the train therefore through 120 inches, the engine yielded, in excess of what was required, 71 units of work to each square inch of piston, or a total of 71 × 260 = 18,460 units. A train of 200 tons weight would have the same accumulated work put into it by a fall through ½ an inch, so that the varying tractive power in the engine produced effects in the train such as would be produced by a depression of ½ an inch in every 25 feet, the distance covered during one revolution of the driving wheel. Similarly, at 35 miles per hour, the varying amounts of tractive power represented changes such as would be produced by the train descending about one inch, and again rising one inch, in every 25 feet of its advance. And at 52 miles per hour, the same variations were equivalent to a descent, and then an ascent of the train, in every 25 feet of its advance, of nearly 2 inches.

Some admissions had been made by Mr. Bidder which were valuable to the cause advocated in the Paper, inasmuch as he had stated, as the result of his great experience of two-cylinder locomotives, that violent oscillations did sometimes occur when least expected, as when the engine was travelling on a straight road, and that road an excellent road; thus fully confirming the opinion, that great causes of oscillation existed essentially in the ordinary two-cylinder locomotive, so that at high speeds great oscillation would occur, however perfect the road on which it travelled.

He thought he had established, if not a certainty, at least the probability, that were the permanent way mathematically perfect, locomotive engines of the ordinary construction would create lateral and oscillatory movements of a grave character at high speeds, and also results similar to those produced by numerous small depressions in the level of the rails.

December 9, 1862.

CHARLES HUTTON GREGORY, Vice-President,
in the Chair.

The discussion upon the Paper No. 1,076, "On some of the Internal Disturbing Forces of Locomotive Engines," by Mr. A. W. Makinson, was continued throughout the evening, to the exclusion of any other subject.

ANNUAL GENERAL MEETING.

December 16, 1862.

JOHN FOWLER, M.P., Vice-President,
in the Chair.

MESSRS. T. M. SMITH, HARRISON HAYTER, and W. HALL, were requested to act as Scrutineers of the Ballot, for the election of the President, Vice-Presidents, and other Members and Associates of Council.

The list of the attendances of the Members of Council for the past year was read, and the Ballot was commenced; the balloting-papers being sent for examination, at intervals of fifteen minutes, in order to expedite the labours of the Scrutineers.

The Annual Report of the Council, on the proceedings of the Institution during the past year, was read.

Resolved,—That the Report of the Council be received and approved; and that it be referred to the Council, to be printed and circulated with the Minutes of Proceedings, in the usual manner.

Resolved,—That the thanks of the Institution are due, and are presented to Messrs. Stileman and Bramwell, for the readiness with which they undertook the office of Auditors of Accounts, and for the clear statement they have laid before the Meeting; and that Messrs. Bramwell and John V. N. Bazalgette be requested to undertake the office of Auditors for the ensuing year.

The Telford and Watt Medals, the Stephenson and Miller Prizes in money, and the Council and Manby Premiums of Books, which had been awarded, were presented.

Resolved,—That the thanks of the Institution are justly due, and are presented to the Vice-Presidents and other Members of the Council, for their co-operation with the President, their constant attendance at the Meetings, and their zeal on behalf of the Institution.

Mr. Gregory, Vice-President, returned thanks.

Resolved unanimously,—That the cordial thanks of the Meeting be given to Mr. Hawkshaw, President, for his strenuous efforts in the interests of the Institution, for his extraordinary attention to the duties of his office, and for the urbanity he has at all times displayed in the Chair.

Mr. Fowler, Vice-President, returned thanks, in the unavoidable absence of the President.

Resolved unanimously,—That the cordial thanks of the Meeting be given to Mr. Charles Manby, the Honorary Secretary, and to Mr. James Forrest, the Secretary, for their constant zeal and devotion to the interests of the Institution, the ability displayed by them in the execution of their duties, and their attention to the individual wishes of the Members.

Mr. Manby and Mr. Forrest severally returned thanks.

The Ballot having been open more than an hour, the Scrutineers, after examining the papers, announced that the following gentlemen were duly elected to fill the several offices in the Council for the ensuing year:—

President.

JOHN HAWKSHAW, F.R.S.

Vice-Presidents.

John Fowler.
Charles Hutton Gregory.
John Robinson M'Clean.
John Scott Russell, F.R.S.

OTHER MEMBERS OF COUNCIL.

Members.

Sir W. G. Armstrong, C.B., F.R.S.
Nathaniel Beardmore.
Joseph Cubitt.
Thomas Elliot Harrison.
Thomas Hawksley.
George Willoughby Hemans.
John Murray.
George Robert Stephenson.
Charles Vignoles, F.R.S.
Joseph Whitworth, F.R.S.

Associates.

John Towlerton Leather.
Frederick Marrable.

Resolved,—That the thanks of the Meeting be given to Messrs. Smith, Hayter, and Hall, the Scrutineers, for the promptitude and efficiency with which they have performed the duties of their office, and that the ballot-papers be destroyed.

ANNUAL REPORT.

SESSION 1862-63.

THE term of office of the present Council being about to expire, it becomes their duty to present a Report to the general body upon the state of the Institution, and particularly upon the proceedings of the past year; and they hope to show, that its interests have been satisfactorily advanced since the conduct of its affairs was committed to them.

The actual business of the Institution will alone be dealt with in this Report. Commencing, then, with what must ever be considered to stand first in order of importance—the Ordinary General Meetings—it may be stated, that the principal Papers read during the past Session were:—"The Hooghly and the Mutla," by J. A. Longridge, (M. Inst. C.E.); "On Measuring Distances by the Telescope," by W. B. Bray, (M. Inst. C.E.); "On the Discharge from Under-drainage, and its effect on the Arterial Channels and Outfalls of the Country," by J. Bailey Denton, (M. Inst. C.E.); "On the Form and Materials for Iron-Plated Ships, and the points requiring attention in their Construction," by J. D'A. Samuda, (M. Inst. C.E.); "Description of the Loch Ken Viaduct, Portpatrick Railway," by E. L. J. Blyth, (M. Inst. C.E.); "Description of the Centre Pier of the Saltash Bridge on the Cornwall Railway, and of the means employed for its Construction," by R. P. Brereton, (M. Inst. C.E.); "Description of the Delta of the Danube, and of the Works, recently executed, at the Sulina Mouth," by Sir C. A. Hartley, (M. Inst. C.E.); "Description of Works at the Ports of Swansea, Blyth, and Silloth," by J. Abernethy, (M. Inst. C.E.); "Railway Accidents, their Causes and means of Prevention," by J. Brunlees, (M. Inst. C.E.); "Railway Accidents, showing the bearing which existing legislation has upon them," by Captain Douglas Galton, R.E., (Assoc. Inst. C.E.); "On the Sea Dykes of Schleswig and Holstein, and on Reclaiming Land from the Sea," by J. Paton, (M. Inst. C.E.); "On Reclaiming Land from Seas and Estuaries," by J. Oldham, (M. Inst. C.E.); "On Reclaiming Land from Seas and Estuaries," by J. H. Müller, (of the Hague); "The Malta and Alexandria Submarine Telegraph Cable," by H. C. Forde, (M. Inst. C.E.); and "On the Electrical Tests employed during the construction of the Malta and Alexandria Telegraph, and on insulating and protecting Submarine Cables," by C. W. Siemens, (M. Inst. C.E.)

A brief epitome of some of these will bring to your recollection the amount of useful information thus collected, the variety of the subjects treated, and the animated discussions which arose on several of the Engineering topics of the day.

In his "Description of the Delta of the Danube, and of the Works, recently executed, at the Sulina Mouth," Sir Charles Augustus Hartley, the Chief Engineer of the European Commission of the Danube, first gave an account of the chief characteristics of the river through its delta, and then of the three principal channels, or branches, with their numerous outlets, by which it reached the sea. It was stated, that great diversity of opinion existed as to the relative merits of these several branches, or mouths, and their capability for improvement. Eventually, after considerable discussion, it was resolved to improve the bar channel of the Sulina, by guiding piers of a temporary character, in order to afford the speediest relief to the navigation in the cheapest manner; but it was agreed at the time, that this decision should not prejudice the choice of the mouth to be selected for permanent treatment. A detailed description of the works, and of their mode of execution, then followed, from which it appeared that the length of the north pier was 4,631 feet, and of the south pier 3,000 feet. They were built in a depth of water varying from 6 to 20 feet, at a cost of about £80,000; a sum which did not exceed the amount paid in one year for lightening vessels over the bar. The changes which had taken place at the Sulina mouth, consequent on the projection of the piers, were then noticed. At the time when the works were commenced, the depth over the bar was only 9 feet, whereas after their completion, when the whole force of the river current was concentrated directly on the bar, there never was a less depth than 16½ feet, and it frequently amounted to 17½ feet, over a navigable width of 500 feet. These works, as well as being of political importance, possessed great engineering interest, and had been completed up to their present stage most successfully.

In the Paper "On Reclaiming Land from Seas and Estuaries," by Mr. John Müller (of the Hague), it was stated that, the reclamation of large areas was the least expensive in the end, and that the object should be to enclose the largest area, with the shortest length of bank, and the smallest average cross section. These points were regulated by the direction and situation of the sea banks; and the conditions to be observed in determining these preliminaries were then noticed. The defences of the slopes of the works alluded to consisted of clay and grass flags, wood, and stone. A minute description was given of the protection by fascine work, as well as of the stone defences, as commonly constructed by the Dutch. It was observed, that creeks should be crossed, if possible, at right angles, and at the same level; and in Holland, the plan adopted in closing them was, to raise the bottom uniformly to the level of low water, by means of cradles, the construction and mode of applying which were minutely detailed, and the precautions to be adopted were strongly enforced.

Mr. Paton, in his Paper "On the Sea Dykes of Schleswig and Holstein, and on Reclaiming Land from the Sea," spoke of the vast extent of land enclosed by these dykes, as being probably greater than any similarly protected in other parts of the world. An account was then given of the principal storm floods which had occurred on the Danish coasts, and of the changes and variations to which these coasts had been subjected, during a period of two thousand years. The construction of the dykes, the materials employed, the mode of formation, and the various plans of protection, were then treated of in detail. Numerous examples were adduced of the advantage of projecting arches, or groynes, especially in exposed localities. The Author further urged that no other engineering works were of greater importance than reclamations from the sea; and as it was believed there were still 600,000 acres of land in Great Britain and Ireland, worth from £20 to £60 per acre, which might yet be reclaimed, besides similar tracts in other countries; hence he contended that the magnitude of the results could scarcely be overrated.

Mr. Oldham, in his Paper on the same subject, first alluded to the system of 'warping,' as commonly practised on the Trent, the Ouse, and the Don, and then explained the phenomena of tidal deposits and accretions in the formation of new land. In practical operations on the River Humber, it was stated that a year or two before embanking, endeavours were made to secure a thoroughly uniform surface on the land to be enclosed. In illustration, the works of the last embankment, for enclosing 700 acres of new accretion, at Small Island in the Humber, were described. After this land had been reclaimed about three years, there was a spontaneous growth of white clover, and the tenants admitted that they frequently obtained six imperial quarters of grain per acre; whilst flax was produced in large quantities and of fine quality, as well as potatoes, turnips, mangold-wurzel, and other root crops.

In the "Description of Works at the Ports of Swansea, Blyth, and Silloth," Mr. Abernethy gave an account of the past and present engineering history of those ports, as well as of the works connected with them.

With regard to Swansea, it was stated, that the effect of the piers, completed in the year 1800, from the designs of Captain Huddart, F.R.S., had been to lower the bar and to drive it out to sea. The Reports submitted by Mr. Telford, in 1827, and by Mr. Jesse Hartley, in 1831-32, were then alluded to; and the Author remarked that, in his opinion, it was fortunate the works for the 'canalisation' of the river, as suggested by Mr. Hartley, had not been carried out. In 1845, under the direction of Mr. Rendel, the construction of an entrance, with a double cill, was proceeded with, as a preliminary step to the conversion either of the river, or of the town reach, into a float; but of this work the masonry alone was executed. When the Author was first consulted, in 1849, he proposed the formation of a dock on the site of the town reach, or old bed of the river, and he subsequently carried out several works, including a lock and float, and a half-tide basin, besides straightening the lower portion of the river, and deepening both it and the new cut by dredging. By these means the depth of the entrance channel had been increased 4 feet, since 1850. But the most important work, connected with the port, was the range of floating dock accommodation called the South Dock, which had been formed on the foreshore of the sea, beyond high-water mark. These works comprised a trumpet-mouth entrance basin, to an outer, or half-tide dock, with a single pair of gates, 70 feet in width, between them, and of an inner dock, connected with the outer dock by a lock, divided by intermediate gates; the total cost amounted to £169,073. Details were then given of the manner in which the works had been executed, and of the materials of which they had been constructed.

The successful application of hydraulic power for working the ordinary hand gear, for opening and closing the gates at the float lock, and at the lock at Newport, led to the adoption of the same plan at the new dock entrance at Swansea; as, in case of any accident happening to the hydraulic machinery, the usual means remained available. The time employed in opening, or in closing the gates, was about two minutes and a half. The same system was also employed for opening and shutting the bridges and sluices, for working the capstans, for discharging ballast, and for loading coal, as well as for the shipping and discharging of general cargoes. It was found that about 1,000 tons of coal per day could be shipped by each machine, at a cost for hydraulic power alone of about one farthing per ton.

At Blyth, the result of the construction of an eastern breakwater and of a western half-tide training wall was said to have been to increase the velocity of the outgoing current to 5 knots per hour, by which the bar at the entrance was entirely removed, and a depth at low water of from 8 to 9 feet, or 4 feet more than before, was maintained throughout the channel.

It was stated, that the general design of the works at Silloth, on the Solway Frith, was due to Mr. John B. Hartley, but their execution had been intrusted to Mr. Abernethy. They comprised a pier, or jetty, on the seaward side of the dock entrance, a channel parallel with the jetty, an embankment on the foreshore, enclosing the entrance to the dock, and the dock itself. These works indicated that great care must be exercised, in projecting solid moles from the foreshore of an estuary, on a sandy coast, as an entrance to a port. The entrance gates, cranes, and coal-hoists were all worked by Sir William Armstrong's hydraulic machinery; but the coal-hoists were exceptional, and deserved special notice, as involving the question of the relative capabilities and advantages of a high, or a low level system for loading coal.

The value of this communication was much enhanced, by the complete series of drawings illustrating it.

Mr. Bailey Denton's Paper "On the Discharge from Under-drainage, and its effect on the Arterial Channels and Outfalls of the Country," contained deductions from a series of experiments made at Hinxworth, to ascertain the relative fall of rain on the surface, and the discharge of water from the under-drains. The general results of under-drainage, on the arterial water-supply and outfalls, seemed, to the Author, to be—first, to render the surface more capable of absorbing the rain that fell upon it;—secondly, to lower the discharge of the upper surface springs in a slight degree; and thirdly, to withdraw from the power of evaporation, all the water which the under-drains discharged.

The Paper on "The Hooghly and the Mutla," by Mr. Longridge, contained, first, a statement of the commercial importance of the Port of Calcutta; secondly, a brief account of the present mode of transport of the traffic to the port, and the modification of it by works now in progress; thirdly, a sketch of the physical features of the two outlets—the Hooghly and the Mutla; and fourthly, remarks on the past and present state of those rivers, as navigable channels, together with a consideration of remedial measures. The Author urged the establishment of a new port at the head of the Mutla, which was an arm of the sea, rather than a river, as it was believed it would lead to a saving of two days in the time of the postal and passenger service between this country and Calcutta; for whereas, in general, a ship drawing 24 feet could only get to sea from Calcutta by the aid of steam, and, under the most favourable circumstances, in from three to four days, or during the south-west monsoon in five days, a similar vessel could at all times get to sea from the head of the Mutla, in from eight to ten hours.

It was urged by Mr. Samuda, in his Paper "On the Form and Materials for Iron-Plated Ships, and the Points requiring attention in their Construction," that four indispensable conditions must be kept in view: first, a superiority in speed over the best timber-built frigates afloat; secondly, complete protection over their entire length; thirdly, armour capable of rapid replacement, or repair; and fourthly, armour entering into the construction of the ship, so as to add to the strength of the fabric. He examined how far these conditions had been attained in the ships already launched, or being built; and next proceeded to describe an arrangement by which a perfect ship, without armour, was first made, then a complete armour case was attached through five longitudinal ribs, or bars of rolled iron, riveted outside the framework, but under the ordinary skin plates, without interfering with the joints, or fastenings of the ordinary skin of the vessel. The edges of the armour plates were brought close together, and the vertical butt joints of each plate were made to break joint with the skin plates. This important subject was not by any means exhausted by the arguments either in the Paper, or in the discussion upon it.

"Railway Accidents" formed the subject of two Papers; one by Mr. Brunlees, in which the causes of accidents were mostly treated of; and the other by Captain Douglas Galton, who devoted himself, principally, to showing the bearing which existing legislation has upon them.

Mr. Brunlees took as the basis of his Paper, the Reports of the Inspecting Officers of the Board of Trade, for the seven years from 1854 to 1860. During this period 540 accidents had occurred, of which 11 per cent. was attributed to the permanent way, 7 per cent. to the rolling stock, and 76 per cent. to the management, including insufficient means for securing safety, leaving only 6 per cent. as not ascertained. The causes of the accidents were then referred to in detail; but the Author stated, that as they were sufficiently apparent, he would not attempt, by theory, to establish rules for their prevention.

Captain Galton submitted the same series of accidents to another analysis; taking, first, those which could not be guarded against, and secondly, those which were within the control of the managing, or working staff; and including in the first class, accidents arising from engines and carriages leaving the rails, or from fractures of machinery, and in the second class, collisions of every description. It appeared to him that a large proportion of the so-called accidents were due to preventible causes, and that out of 319 collisions, only 16 were attributable to purely accidental causes, whilst 183 were assigned to the negligence of inferior servants, and 120 to the manner in which the traffic was conducted, and which ought not, therefore, to have occurred. The greater comparative safety of foreign railways was traced to differences in the conditions of the traffic and of the management, as well as in the habits of the people. Captain Galton calculated, from the sum paid by British Railway Companies for compensation, that an insurance of one twenty-fourth part of a farthing per passenger per mile would, on the average of all lines, cover the cost of Railway Accidents. The existing law, affecting Railway Companies as carriers, was then alluded to; and it was urged that freedom from accidents was not to be obtained by Government interference, but by an effective and responsible internal management, which would enforce the greatest punctuality and care in working the traffic, and would maintain the strictest discipline amongst the servants employed.

These Papers, although very interesting, still leave the subject of Railway Accidents to be treated from a purely engineering point of view, and it is hoped that this branch of the question will soon be further discussed.

In Mr. Forde's Paper on "The Malta and Alexandria Submarine Telegraph Cable," an account was given of the manufacture of the cable, and of the reasons which led to the adoption of a particular form and size. Originally intended to be employed between Falmouth and Gibraltar, and then proposed to be used to join Rangoon and Singapore, the cable was ultimately laid between Malta and Alexandria. The operation of paying out, and the mechanism by which it was effected, were minutely described; and it was observed that as the cable was submerged, its electrical condition invariably improved; the rate of working was about five words per minute through a length of 1,100 knots.

Mr. Siemens in his Paper "On the Electrical Tests employed during the construction of the Malta and Alexandria Telegraph, and on insulating and protecting Submarine Cables," stated that, in the course of the manufacture of the cable, the chief object was to obtain throughout strictly comparative results. For this purpose a standard measure of resistance was adopted,—as suggested by Dr. Werner Siemens—and the results were given in tables, as well as exhibited graphically in diagrams. They showed a decided improvement in the insulation, after submersion. Although the line was divided into three electrical circuits, messages were transmitted mechanically and instantaneously, at the intermediate station, by a system of double relay, or translation. Attention was then directed to the insulating covering of cables, and the relative merits of india-rubber and of gutta-percha, as well as of compounds of the two, were commented upon; their absorption of water, and the insulating and inductive capacities of wires covered with these different substances, being made the subject of experiment. The outer covering of cables was also taken into consideration, and a sheathing was proposed, which confirmed the application, under the influence of great pressure, of from three to six strips of copper, or other metal, secured spirally round the cable, and made to overlap each other for nearly half their breadth; the pressure applied being sufficient to crush, or socket the one metal down, where it was covered by the other.

The following Telford and Watt Medals, Stephenson and Miller Prizes in money, and Council and Manby Premiums of Books, have been awarded to the Authors of some of these communications:—

1. A Telford Medal, the Manby Premium, in Books, and a Stephenson Prize of Twenty-five Guineas, to Sir Charles Augustus Hartley, M. Inst. C.E., for his "Description of the Delta of the Danube, and of the Works, recently executed, at the Sulina Mouth."
2. A Telford Medal, and a Miller Prize of Fifteen Guineas, to John Henry Muller (of the Hague), for his Paper "On Reclaiming Land from Seas and Estuaries."
3. A Telford Medal, and a Miller Prize of Fifteen Guineas, to John Paton, M. Inst. C.E., for his Paper "On the Sea Dykes of Schleswig and Holstein, and on Reclaiming Land from the Sea."
4. A Telford Medal, to James Abernethy, M. Inst. C.E., for his "Description and Illustrations of the Works at the Ports of Swansea, Blyth, and Silloth."
5. A Telford Medal, to John Bailey Denton, M. Inst. C.E., for his Paper "On the Discharge from Under-drainage, and its effect on the Arterial Channels and Outfalls of the Country."
6. A Watt Medal, to Joseph D'Aguilar Samuda, M. Inst. C.E., for his Paper "On the Form and Materials for Iron-Plated Ships, and the Points requiring attention in their Construction."
7. A Council Premium of Books, to Jas. Brunlees, M. Inst. C.E., for his Paper on "Railway Accidents—their causes and means of prevention."
8. A Council Premium of Books, to Capt. Douglas Galton, R.E., F.R.S., Assoc. Inst. C.E., for his Paper on "Railway Accidents, showing the bearing which existing legislation has upon them."
9. A Council Premium of Books, to Henry Charles Forde, M. Inst. C.E., for his Paper on "The Malta and Alexandria Submarine Telegraph Cable."

10. A Council Premium of Books, to Charles William Siemens, F.R.S., M. Inst. C.E., for his Paper "On the Electrical Tests employed during the construction of the Malta and Alexandria Telegraph, and on insulating and protecting Submarine Cables."
11. A Council Premium of Books, to James Atkinson Longridge, M. Inst. C.E., for his Paper on "The Hooghly and the Mutla."
12. A Council Premium of Books, to James Oldham, M. Inst. C.E., for his Paper "On Reclaiming Land from Seas and Estuaries."

It will be observed that, for the first time, premiums in money have been awarded; and it will be for the in-coming Council to consider how far the increased value of the premiums, by in some degree offering remuneration for the time devoted to the study of the subjects, will induce the presentation of complete and well-composed Papers for reading at the Meetings.

Since the date of the last Report, Vol. xix. of the Minutes of Proceedings, containing 700 pages, has been issued. Vol. xx., consisting of nearly 600 pages, is complete, and will be forwarded to the Members in a short time. Considerable progress has also been made with volume xxi. for the last Session. The publication of these volumes has been retarded by the non-receipt of information required and corrections requested,—more especially with respect to the Memoirs of deceased Members. It has indeed been necessary at last to omit some memoirs, as the relatives and friends have, notwithstanding repeated requests, neglected to furnish any particulars. It is under consideration, whether it may not be advantageous in future to publish the Memoirs as an Appendix to the volume, rather than allow them to occasion delay in the publication of the Minutes of Proceedings.

During the past session, the custom of assembling the Members at dinner was revived, and advantage was taken of the presence in London, on the occasion of the International Exhibition, of many foreigners of scientific reputation, to invite them as guests. The dinner was so successful, that it is suggested to repeat it annually; and it may be fairly anticipated, that as the Members increase in number, so will the Annual Dinner be looked forward to as another general meeting of a more social character.

The Institution was also able to be very useful to many foreign engineers and scientific men who visited this country; and communications have been established which will be mutually beneficial, and will render the mere title of Member of this Institution, the best passport for all Engineers when travelling in foreign countries.

The tabular statement of the transfers, elections, deceases, and resignations of Members of all classes, during the years 1860-61 and 1861-62, (taking into consideration the names which have been erased from the Register), appears thus:—

—	Honorary Members.	Members.	Associates.	Graduates.	Annual Increase.
1860-61.					
Transferred to Members . .	..	..	2	..	
Elections	..	24	45	..	69 − 54 = 15
Deceases	2	9	12	..	
Resignations	..	2	7	1	54
Erased from Register . . .	..	1	18	2	
1861-62.					
Transferred to Members . .	..	..	7	..	
Elections	..	35	37	..	73 − 18 = 55
Restored to the List	..	1	..	..	
Deceases	2	7	6	1	18
Resignations	..	..	2	..	
Members of all Classes on the Books, November 30, 1862 .	20	405	565	10	= 1000

As the total number of Members of all classes on the 30th of November 1857 was 835, it appears that there has been an increase of nearly 20 per cent. in the last five years, of which about 6½ per cent. occurred in the past twelve months.

If the Honorary Members and Graduates are omitted from the calculation, the annual increase of Members and Associates stands thus:—

YEARS.	Members Elected.	Associates Elected.	Total Elected.	Deceases, Resignations, and Erasures.	Effective Increase.
1857	12	57	69	23	46
1858	11	25	36	13	23
1859	16	41	57	20	37
1860	23	39	62	25	37
1861	24	45	69	49	20
1862	35	37	72	15	57

The following Associates having tendered their resignations, have been permitted to retire from the Institution:—Messrs. William Southcote Inman and Francis Cranmer Penrose.

The deceases during the past year have been H. R. H. The Prince Consort, and Peter Barlow, Honorary Members; James John Berkley, James Cooper, Henry Hind Edwards, John Edward

Errington, Joseph Lane Manby, James Walker, and William Weallens, Members; Major John Fraser Lodington Baddeley, R.A., Captain Carlton Thomas Collingwood, Colonel Samuel Colt (U. S.), Robert Cowen, John Evans, and John Withers, Associates; and John Brannis Birch, Graduate.

The Memoirs of our late friends will be found in the Appendix to this Report.

In this list there will be observed the names of two Members well known in this Institution—Mr. J. E. Errington, Vice-President, and Mr. James Walker, Past-President.

Mr. Errington had long occupied a distinguished position in the profession. In conjunction with his partner, the late Mr. Joseph Locke, he had been actively and successfully engaged, during the last thirty years, in the execution of important works, and had materially contributed to the extension of that vast network of railways now covering the United Kingdom, which is one of the distinguishing features of the present age. Mr. Errington has been taken from among us, just at the period when we might have looked forward to his having more leisure, which would have enabled him to impart to the Institution the results of his varied practice, as he had promised to do, when he occupied the position of Vice-President. It is hoped that among his pupils, there are several young Engineers who, mindful of his constant desire to advance their position, will lay before the meetings, plans and descriptions of the works upon which they have been engaged under him, and thus, while benefiting the Institution, they will evince their gratitude to the memory of him who had always their well-being in view.

Mr. Errington demonstrated his anxiety for the advancement and prosperity of this Institution, by bequeathing to it the sum of One Thousand Pounds, free of legacy duty, for the general purposes of the Society.

Mr. Walker was one of the oldest Members of the profession, having been in active practice as an Engineer for upwards of sixty years. He was also one of the earliest Members of the Institution, having joined it in the year 1823, and, after the death of Mr. Telford, he became its President. For a period of eleven years, during which he so ably conducted its proceedings in that capacity, he was most devoted to its interests, and to his zeal and energy must be greatly attributed the eminent position it held, on his retiring from the chair in 1845. Mr. Walker's name was associated with many engineering works in England and Scotland, including light-houses, harbours, bridges, embankments, and drainage. His opinion was much valued by the Elder Brethren of the Trinity House, by the Lords of the Admiralty, and by the Corporation of the City of London, and it must not be forgotten, especially at the present moment, that twenty years ago he laid down lines for embanking each side of the River Thames, which have never been improved. Many Members of the profession, including Messrs. Burges, Bidder, Hawkshaw, M'Clean, Borthwick, and Hartley, were engaged with and under Mr. Walker, and to the experience they gained on his works may be partly ascribed the eminence they have attained.

Mr. Walker left at Mr. Burges' disposal the twenty-five remaining copies of Telford's "Life and Works," as well as the copyright and the copper-plates, and the Council have much pleasure in announcing that Mr. Burges has, in the most handsome and liberal manner, presented them to the Institution for the purpose of being used as Premiums.

The amount of arrears of subscriptions for 1862, due November 30th is:—

	£.	s.	d.	£.	s.	d.
From Members of all classes, residing abroad	56	3	6			
From Members of all classes, residing in the United Kingdom	219	19	6			
				276	3	0
The amount of arrears for the years 1860 and 1861, was—						
From Members of all classes, residing abroad	40	8	6			
From Members of all classes, residing in the United Kingdom	110	5	0			
				150	13	6
Total				£426	16	6

Although there is an increase in the amount of arrears, as compared with the previous year, notwithstanding every effort having been made to obtain payment of the sums due, yet the financial position of the Institution, as shown by the Abstract of Receipts and Expenditure appended to this Report, is most satisfactory. The total amount received under the head of "Subscriptions and Fees" does not quite equal the return of the previous year, partly owing to one Member only having paid a life-composition, but mainly from the non-payment of arrears, for the current subscriptions have exceeded those of the previous year by from 7 to 8 per cent. The receipts from other subsidiary sources remain about the same. During the last twelve months, there has been a considerable increase in the income arising from the dividends upon the several stocks held by the Institution. With regard to the expenditure, the establishment charges are somewhat higher. And a very large sum, upwards of £1,000, has been paid on account of Minutes of Proceedings. Still, however, the total disbursements have been less than the receipts from subscriptions and fees alone, without including the other sources of revenue.

The executors of the late Mr. Joseph Miller have transferred into the name of the Corporation of the Institution of Civil Engineers £2,133. 6*s.* 8*d.* Reduced Three per Cent. Annuities, representing the sum of £2,000—the dividends upon which were directed to be paid to Mr. John Miller during his life,—which was bequeathed "to be applied for the general use and benefit of the Institution, in such manner as the managing body for the time being may think proper."

It may be remembered that, at the date of the last Annual Report, there was on deposit at the Union Bank a sum of £1,221. 19*s.* As there was no immediate prospect of this money being required for the current expenses, and as the rate of interest then obtained at the Bank was low, it was thought that the time had arrived when a further investment could be safely made. Accordingly this amount, together with £322. 4*s.* 5*d.* withdrawn from the general account at the banker's, was invested in the purchase, at par, of £1,500 Great Northern Railway Company, Four per cent. Debenture Stock. Subsequently, £1,000 of this stock has been assigned as representing the Errington Bequest. It having been found that there was a considerable balance of dividends arising from the Telford Fund, which had not as yet been expended in Annual Premiums, in accordance with the directions of the testator, it was deemed advisable to consult the Honorary Solicitor of the Institution on the subject. Acting on the recommendation of Sir Roundell Palmer, Her Majesty's Solicitor-General, this balance, amounting to £1,669. 8*s.* 6*d.* has been invested in the purchase of £1,775. 19*s.* 8*d.* Reduced Three per Cent. Consolidated Annuities.

The Funds now under the charge of the Institution, in addition to a balance in the hands of the Treasurer of £456. 8*s.* 2*d.* and of an amount on deposit on account of the Building Fund of £447. 7*s.*, are as follows:—

I. GENERAL FUNDS.

		£.	*s.*	*d.*	£.	*s.*	*d.*
1. Stephenson Bequest, North Eastern Railway Company Four per Cent. Debenture Stock		2,000	0	0			
2. Miller Bequest, Reduced Three per Cent. Consolidated Annuities		2,133	6	8			
3. Errington Bequest, Great Northern Railway Company Four per Cent. Debenture Stock		1,000	0	0			
4. Institution Investments, Norfolk Railway Company Four per Cent. Debenture Stock	£2,000						
" " Great Northern Railway Company, Four per Cent. Debenture Stock	£1,000						
	——	3,000	0	0			
					8,133	6	8

Together yielding an annual income, at the present time, of £292. 12*s.*

II. TRUST FUNDS.

	£. s. d.	£. s. d.
1. Telford Fund,—"given in trust, the Interest to be expended in Annual Premiums, under the direction of the Council,"—Three per Cent. Consols	2,551 15 10	
" " Three per Cent. Annuities .	2,342 17 1	
		4,894 12 11
" " Balance of Dividends, not yet expended in Annual Premiums, standing in Three per Cent. Consols .		1,775 19 8
2. Manby Donation,—"to form a fund for an Annual Premium, or Premiums, for Papers read at the Meetings,"—Norfolk Railway Company Five per Cent. Preference Stock. .		200 0 0
3. Miller Fund,—"for providing Premiums, or Prizes, for the Students of the said Institution, upon the principle of the Telford Fund,"—Lancashire and Yorkshire Four per Cent. Debenture Stock	£2,000	
" " Norfolk Railway Company Four per Cent. Debenture Stock	£1,100	
		3,100 0 0
Total . .		£9,970 12 7

The Telford Fund produced in the last financial year £141. 6*s*. 8*d*. —irrespective of the balance of dividends not yet expended in Annual Premiums—the Manby donation realised in the same period £9. 12*s*. 6*d*. and the Miller Fund £119. 6*s*. 11*d*.

It will be for the succeeding Council to consider in what manner these several funds, especially the conditional trusts, can be best applied, in furthering the object of the Incorporation, which is stated in the Charter to be "for the general advancement of Mechanical Science, and more particularly for promoting the acquisition of that species of knowledge which constitutes the profession of a Civil Engineer."

In preparing the balloting list it was necessary, owing to the decease of Mr. Errington, to nominate another gentleman to fill the vacant office among the Vice-Presidents. Mr. John Scott Russell, the senior Member of Council, has been selected. The nine remaining Members of the Council are all eligible and are submitted for re-election; and, in accordance with the Bye Laws, the names of three other Members, Messrs. Abernethy, W. H. Barlow, and N. Beardmore, all of whom have consented to serve, have been added to the list.

The two Associate Members of Council retire annually. The names of four gentlemen have to be inserted in the list for your consideration, and on this occasion Messrs. J. T. Leather, F. Marrable, C. Waring, and Colonel Sale, have consented to be put in nomination.

The Council believe that the past Session may be looked upon with satisfaction, for the increase in the number of the Members, and for the nature of its general proceedings; and they regard the present success and well-being of the Institution, as the best guarantees for its future and long-continued usefulness.

ABSTRACT *of* RECEIPTS *and* EXPENDITURE.

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RECEIPTS.

Dr.	£.	*s.*	*d.*	£.	*s.*	*d.*
To Deposit at Union Bank	1,000	0	0			
— Balance of Petty Cash, Nov. 1, 1861, in the hands of the Secretary	10	19	2			
— Balance in the hands of the Treasurer	668	9	3			
				1,679	8	5
— Subscriptions and Fees :—						
Arrears	151	4	0			
Current	2,382	19	6			
Subscription, 1863 (in advance)	2	12	6			
Fees	223	13	0			
Life	26	5	0			
				2,786	14	0
— Publication Fund				44	2	0
— Council Premium Fund				45	0	0
— Publications :—Sale of Transactions				73	4	4
— Telford Fund :—						
Dividends—1 year, on £2,551. 15*s.* 10*d*, Three per Cent. Reduced Consols	73	13	8			
Ditto, on £2,342. 17*s.* 1*d.*, Three per Cent. Reduced Annuities	67	13	0			
				141	6	8
— Manby Premium :—						
Dividends—1 year, on £200, Norfolk Railway Company, Five per Cent. Preference Stock				9	12	6
— Stephenson Bequest :—						
Dividends—1 year, on £2,000, North Eastern Railway Company, Four per Cent. Debenture Stock	77	0	0			
Balance of Deposit Account, after purchase of the above Stock	23	16	4			
				100	16	4
— Miller Fund :—						
Dividends—1 year, on £2,000, Lancashire and Yorkshire Railway Company, Four per Cent. Debenture Stock	76	19	11			
Ditto, on £1,100, Norfolk Railway Company, Four per Cent. Debenture Stock	42	7	0			
Balance of Deposit Account, after purchase of the above Stocks	18	5	0			
				137	11	11
— Miller Bequest :—						
Balance of ½-year's Dividends on £2,133. 6*s.* 8*d.*, Reduced Three per Cent. Annuities	23	1	3			
½-year's Dividends on £2,133. 6*s.* 8*d.*, Reduced Three per Cent. Annuities	30	16	0			
				53	17	3
— Institution Investments :—						
Deposit Interest—½ year on £1,221. 19*s.*	18	2	7			
Dividends—1 year on £2,000, Norfolk Railway Company, Four per Cent. Debenture Stock	77	10	0			
Ditto, 126 days on £1,500, Great Northern Railway Company, Four per Cent. Debenture Stock	19	12	5			
				114	15	0
— Errington Bequest				1,000	0	0
				£6,186	8	5

from the 1st DEC., 1861, *to the* 30th NOV., 1862.

PAYMENTS.

Cr.	£.	s.	d.	£.	s.	d.
By House, Great George Street:—						
Rent	360	10	2			
Rates and Taxes	46	6	9			
Insurance	18	19	9			
				425	16	8
— Salaries				475	0	0
— Clerks, Messengers, and Housekeeper				247	2	0
— Wages of Old Messenger, while in Hospital—57 weeks				57	0	0
— Postage and Parcels:—						
Postage	29	2	5			
Parcels	1	0	0			
				30	2	5
— Stationery, Engraving, Printing Cards, Circulars, &c.				60	4	0
— Coals, Candles, Oil, and Gas:—						
Coals	11	0	0			
Candles	0	7	0			
Oil	3	14	3			
Gas	20	10	1			
				35	11	4
— Tea and Coffee				34	8	0
— Library:—						
Books	90	18	1			
Periodicals	19	1	8			
				109	19	9
— Publication, Minutes of Proceedings				1,001	18	2
— Telford Premiums				6	6	0
— Council Premiums				24	1	6
— Manby Premium				10	10	8
— Diplomas				14	8	10
— Manuscripts, Original Papers, and Drawings				4	6	0
— Winding and Repairing Clocks				4	6	0
— Annual Dinner				92	3	8
— Incidental Expenses:—						
Gratuities and Christmas Gifts	1	16	0			
Donation, St. George's Hospital	10	10	0			
Occasional Assistance	4	11	6			
Assistance at Meetings	10	19	6			
Beating Carpets	3	13	6			
Household Utensils, Repairs, and Expenses	40	14	2			
				72	4	8
				£2,705	9	8
— Great Northern Railway Company Debenture Stock:—						
From Deposit at Union Bank	1,000	0	0			
,, Current Account	322	4	5			
				1,322	4	5
— Telford Fund, Balance of Dividends, not yet expended in Annual Premiums				1,669	8	6
— Balance of Petty Cash, Dec. 1, 1862, in the hands of the Secretary				32	17	8
— Balance in the hands of the Treasurer				456	8	2
				£6,186	8	5

Examined and Compared the above Account with the Vouchers and the Cash Book, and find this Account to be correct, leaving a Balance in the hands of the Treasurer of Four Hundred and Fifty-six Pounds, Eight Shillings, and Two Pence.—November 30, 1862.

(Signed) F. C. STILEMAN, } *Auditors.*
F. J. BRAMWELL, }
JAMES FORREST, *Secretary.*

December 13*th*, 1862.

PREMIUMS AWARDED.

SESSION 1861-62.

THE COUNCIL of the Institution of Civil Engineers have awarded the following Premiums:—

1. A Telford Medal, the Manby Premium, in Books, and a Stephenson Prize of Twenty-five Guineas, to Sir Charles Augustus Hartley, M. Inst. C.E., for his "Description of the Delta of the Danube, and of the Works, recently executed, at the Sulina Mouth."
2. A Telford Medal, and a Miller Prize of Fifteen Guineas, to John Henry Müller (of the Hague), for his Paper "On Reclaiming Land from Seas and Estuaries."
3. A Telford Medal, and a Miller Prize of Fifteen Guineas, to John Paton, M. Inst. C.E., for his Paper "On the Sea Dykes of Schleswig and Holstein, and on Reclaiming Land from the Sea."
4. A Telford Medal, to James Abernethy, M. Inst. C.E., for his "Description and Illustrations of the Works at the Ports of Swansea, Blyth, and Silloth."
5. A Telford Medal, to John Bailey Denton, M. Inst. C.E., for his Paper "On the Discharge from Under-drainage, and its effect on the Arterial Channels and Outfalls of the Country."
6. A Watt Medal, to Joseph D'Aguilar Samuda, M. Inst. C.E., for his Paper "On the Form and Materials for Iron-Plated Ships, and the Points requiring attention in their Construction."
7. A Council Premium of Books, to James Brunlees, M.Inst.C.E., for his Paper on "Railway Accidents—their causes and means of prevention."
8. A Council Premium of Books, to Captain Douglas Galton, R.E., F.R.S., Assoc. Inst. C.E., for his Paper on "Railway Accidents, showing the bearing which existing legislation has upon them."
9. A Council Premium of Books, to Henry Charles Forde, M. Inst. C.E., for his Paper on "The Malta and Alexandria Submarine Telegraph Cable."

10. A Council Premium of Books, to Charles William Siemens, F.R.S., M. Inst. C.E., for his Paper "On the Electrical Tests employed during the construction of the Malta and Alexandria Telegraph, and on insulating and protecting Submarine Cables."
11. A Council Premium of Books, to James Atkinson Longridge, M. Inst. C.E., for his Paper on "The Hooghly and the Mutla."
12. A Council Premium of Books, to James Oldham, M.Inst. C.E., for his Paper "On Reclaiming Land from Seas and Estuaries."

SUBJECTS FOR PREMIUMS.

SESSION 1862-63.

THE COUNCIL invite communications on the following, as well as other Subjects, for Premiums:—

For a limited number of Papers of distinguished merit, pecuniary awards will be made, not exceeding in each case Twenty-five Guineas, in addition to the Honorary Premiums. The subjects numbered 14, 18, 28, and 41, have been selected as those upon which, it is hoped, such communications may be received during the ensuing Session. But Papers on other subjects, if of adequate merit, will be taken into consideration in the adjudication of the pecuniary awards.

1. On the Decay of Materials in Tropical Climates, and the methods employed for arresting and preventing it.
2. On the Manufacture of Bricks by machinery, and their comparison with hand-made bricks.
3. On the Methods of constructing Foundations, for large Structures, in deep water, and on the various systems of Driving Piles.
4. On the Construction of Suspension Bridges, with rigid platforms, and the plans of Anchoring the Stay-chains.
5. On the various modes adopted for moving Earth in Tunnels, Cuttings, or Embankments, with the cost.
6. On the Mechanical Methods of Boring and of Sinking large Shafts, of introducing the Tubing and the impervious lining, and of traversing running sand, and other difficult strata.
7. On the Results of Contrivances for facilitating the Driving of Tunnels, or Drifts in Rock.
8. On Locomotive Engines for ascending Steep Inclines, especially when in combination with sharp curves, on Railways.
9. On the Construction of Railway Carriages and Waggons, with a view to the reduction of the gross weight of Passenger and Goods Trains; also of Railway Wheels, Axles, Bearings, Axle Boxes, and Breaks, and of Bearing, Traction, and Buffer Springs; treating particularly, their ascertained duration and their relative friction.

10. On the Working Expenses of Railways, and the influence of the original design and construction.
11. On the Application of the Electric Telegraph to Railway Train Signalling.
12. On the Results of a series of Observations on the Flow of Water from the Ground, in any large district; with accurately-recorded Rain-Gauge Registries, in the same locality, for a period of not less than twelve months.
13. On the Construction of Catchwater Reservoirs in Mountain Districts, for the Supply of Towns, or for Manufacturing purposes.
14. Accounts of existing Waterworks; including the Source of Supply, a description of the different modes of collecting and filtering, the Distribution throughout the Streets of Towns, and the general practical results. (Twenty-five Guineas.)
15. On the Drainage and Sewerage of Large Towns; exemplified by accounts of the systems at present pursued, with regard to the level and position of the outfall, the form, dimensions and material of the sewers, the prevention of emanations from them, the arrangements for connecting the house drains with the public sewers, and the disposal of the sewage, whether in a liquid form, as irrigation, or in a solid form after deodorisation.
16. On the Results of the Employment of Steam Power on Canals, and of other measures for the Improvement of Canals as a means of conveyance for heavy traffic.
17. A History of the successive changes of any Fresh Water Channel,—accompanied by plans and longitudinal and cross sections,—including a description of the drainage area, and the results of a series of consecutive gaugings, with tables of rainfall for a period of not less than twelve months, as well as notices of any works which may have been executed upon it, and of the effects of the works,—such as those relating to Land Drainage—Irrigation—Navigation—Compensation Reservoirs—Permanent and Moveable Dams—&c.
18. A History of any Tidal River, or Estuary,—accompanied by plans and longitudinal and cross sections,—including notices of any works which may have been executed upon it, of the relative effect of Tidal and Fresh Water, and of the effect of Enclosures from the Tidal Area upon the general régime, of Sluicing where applied to the improvement of the entrance or the removal of a Bar, and of Groynes or Parallel Training Walls. Also, of Dredging, with a description of the Machinery employed, and the cost of raising and depositing the material. (Twenty-five Guineas.)

19. On the Results of a Series of Tidal Observations, illustrative of the modifications which the tidal wave undergoes in its passage up and down a tidal river or estuary.
20. On the Construction of Tidal or other Dams, in a constant or variable depth of water.
21. A History of any Harbour, including the reasons for selecting the site, the mode of construction adopted, and the subsidiary works for the convenience of shipping, and for commercial purposes, with the cost, &c.
22. A History of any Refuge Harbour, including the reasons for selecting the site, the mode of construction adopted, its cost, and the time employed in its execution.
23. A History of any Dock, on the course of a Tidal Stream, in communication with Railways and with Inland Navigation, including the reasons for the selection of the site, the mode of construction adopted, the position of the entrance with reference to the direction of the stream, the cost, &c.
24. Descriptions of the various kinds of Machinery in use in the principal Shipping Ports, for the Shipment of Coal; noticing particularly, those in which the greatest expedition is combined with the least amount of breakage of the coal; and also accounts of the means of unshipping and measuring, or weighing the Coal, on its arrival in Port.
25. On the arrangement and construction of Floating Landing-Stages, for passenger and other traffic, with existing examples.
26. On the different systems of Swing, Lifting, and other opening Bridges, with existing examples.
27. On the Construction of Lighthouses; their Machinery and Lighting Apparatus; with notices of the Methods in use for distinguishing the different Lights.
28. On the Results of the use of Tubular Boilers, and of Steam at an increased pressure, for Marine Engines, noticing particularly, the difference in weight and in speed, in proportion to the Horse Power and the Tonnage. (Twenty-five Guineas.)
29. On the relative advantages of the Principle of Expansion, as applied in the Single long-stroke Cylinder Engine, in the Double Cylinder Engine, and in the Three Cylinder Engine; and on the adaptation of the two latter to marine purposes.
30. On the Causes of the alleged Failure in Economising Fuel, in working Steam expansively, and the probable conditions for insuring success.
31. On the Results of the use of Superheated Steam and of Surface Condensation.

32. On the Measure of Resistance to Steam Vessels at high Velocities.
33. On Boiler Inspection as practised in this country and on the Continent, with remarks as to the comparative merits of the two systems.
34. On the construction of, and the comparative duty performed by, modern Pumping Engines for raising Water, for the Supply of Towns, or for the Drainage of Mines; noticing in the latter case, the depth and length of the underground workings, the height of the surface above the sea, the geological formation, the contiguity of streams, &c.
35. On the Results of the use of Pumps of different kinds, for lifting large quantities of water to a limited height, for the purposes of Drainage, or of Irrigation.
36. On Turbines and other Water Motors of a similar character; their construction and performance, and comparison with Water-wheels.
37. On the means of Utilising the products of the Distillation of Coal, so as to reduce the price of Coke; with descriptions of the Ovens, and of the best processes used in Great Britain and on the Continent, in the manufacture of Coke.
38. On the present systems of Smelting Iron Ores, and on the Conversion of Cast Iron into the malleable state, and of the Manufacture of Iron generally, comprising the distribution and management of Iron Works.
39. The Chemical Analysis, and the application to economic purposes, of the Gases generated in Iron Blast Furnaces.
40. On the Manufacture of Iron for Rails and Wheel Tyres, having special reference to the increased capability of resisting lamination and abrasion; and accounts of the Machinery required for rolling heavy Rails, Shafts, and Bars of Iron of large sectional area.
41. On the manufacture of large Masses of Iron for the purposes of Warfare, as Armour Plates, &c. (Twenty-five Guineas.)
42. On the Construction of Rifled and Breech-loading Artillery; and on the Initial Velocity, Range and Penetration of Rifled Projectiles, and the influence of Atmospheric Resistance.
43. On the use of Steel Bars and Plates in Enginework and Machinery, for Boilers and for Ship Building.
44. On Machinery adapted for the Better Separation of the various Substances found in Combination with Metallic Productions.
45. On the Substitution of Machinery for Manual Labour in Mining Operations; and on Hydraulic Machinery in Mines.

46. On the Precautions to be adopted for guarding against Accidents by Fire-damp and After-damp in Mines.
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49 On the Application of Photography to Engineering.
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CHARLES MANBY, *Honorary Secretary.*
JAMES FORREST, *Secretary.*

25, Great George Street, Westminster, S.W.,
October, 1862.

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It has frequently occurred, that in Papers which have been considered deserving of being read and published, and have even had Premiums awarded to them, the Authors may have advanced somewhat doubtful theories, or may have arrived at conclusions at variance with received opinions. The Council would, therefore, emphatically repeat, that the Institution must not, as a body, be considered responsible for the facts and opinions advanced in the Papers, or in the consequent Discussions; and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the discussion and the inquiry; but that such notice, or award, must not be considered as any expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

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"The principal Subjects for which Premiums will be given are:—

"1st. Descriptions, accompanied by Plans and explanatory Drawings, of any work in Civil Engineering, as far as absolutely executed, and which shall contain authentic details of the progress of the work. (Smeaton's Account of the Edystone Lighthouse may be taken as an example.)

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The Communications should be written in the impersonal pronoun, and be legibly transcribed on foolscap paper, about thirteen inches by eight inches, the lines being three-quarters of an inch apart, on the one side only, leaving a margin of one inch and a-half in width on the left side, in order that the sheets may be bound.

The Drawings should be on mounted paper, and with as many details as may be necessary to illustrate the subject. Enlarged Diagrams, to such a scale that they may be clearly visible, when suspended on the walls of the Theatre of the Institution, at the time of reading the communication, should be sent for the illustration of any particular portions.

Papers which have been read at the Meetings of other Scientific Societies, or have been published in any form, cannot be read at a Meeting of the Institution, nor be admitted to competition for the Premiums.

ORIGINAL COMMUNICATIONS,

DRAWINGS, PRESENTS, &c.,

RECEIVED BETWEEN JUNE 30th, 1861, AND JUNE 29th, 1862.

ORIGINAL COMMUNICATIONS.

AUTHORS.

Abernethy, J. No. 1,052.—Description of Works at the Ports of Swansea, Blyth, and Silloth. With a series of Drawings.

Bothams, J. C. No. 1,056.—Account of the Waterworks of the City of Salisbury. With one Plan.

Bray, W. B. No. 1,045.—On Measuring Distances by the Telescope.

Brereton, R. P. No. 1,062.—Description of the Centre Pier of the Saltash Bridge on the Cornwall Railway, and of the means employed for its construction. With a series of Diagrams.

Brunlees, J. No. 1,059.—Railway Accidents—their causes and means of prevention.

Byrne, H. No. 1,051.—On the Use of the Timber of the Palmyra Palm, in the Construction of Bridges. With one Drawing, a model and specimens.

Crawford, R. No. 1,071.—The Railway System of Germany.

Cudworth, W. No. 1,058.—The Hownes Gill Viaduct, on the Stockton and Darlington Railway. With two Drawings.

Denton, J. B. No. 1,046.—On the Discharge from Underdrainage, and its effect on the Arterial Channels and Outfalls of the Country. With a series of Diagrams.

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Fulton, J. No. 1,053.—Description of the Drainage of the Borough of Dundee. With three Drawings.

Galton, Capt. D., R.E., F.R.S. No. 1,067.—Railway Accidents—showing the bearing which existing legislation has upon them.

Hartley, C. A. No. 1,061. Description of the Delta of the Danube, and of the works, recently executed, at the Sulina Mouth. With a series of Diagrams.

Justen, J. No. 1,050.—Observations on the Action of the Tides within Tidal Estuaries.

Landale, J. J. No. 1,060.—The Precautions to be adopted for guarding against accidents from Fire and After-damp in Mines.

Longridge, J. A. No. 1,047.—The Hooghly and the Mutla. With a series of Diagrams.

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Morshead, W. Jun. No. 1,043.—On the Duty of the Cornish Pumping Engine. With two Diagrams.

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Oldham, J. No. 1,055.—On Reclaiming Land from Seas and Estuaries. With two Drawings.

Paton, J. No. 1,065.—On the Sea Dykes of Schleswig and Holstein, and on Reclaiming Land from the Sea. With a series of Diagrams.

Sadasewjee, H. No. 1,069.—On the Drainage of Bombay.

Samuda, J. D'A. No. 1,049.—On the Form and Materials for Iron-Plated Ships, and the points requiring attention in their construction. With one Diagram.

Siemens, C. W. No. 1,072.—On the Electrical Tests employed during the construction of the Malta and Alexandria Telegraph, and on Insulating and Protecting Submarine Cables. With a series of Diagrams.

Williams, A. No. 1,054.—Description of the Sewerage and Drainage Works, at Newport, Monmouthshire. With a series of Diagrams.

CATALOGUE OF PRESENTS.

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——— Natural and Political Observations mentioned in a following Index, and made upon the Bills of Mortality. By Captain John Graunt. 8vo. London, 1676.

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January 13, 1863.

JOHN HAWKSHAW, President, in the Chair.

The following Candidates were balloted for and duly elected:—JOHN WATTS BRASSINGTON, JONATHAN SPARROW CROWLEY, EDWARD GOTTO, and GEORGE WILSON, as Associates.

No. 1,079.—"On Railway Telegraphs, and the Application of Electricity to the Signalling and Working of Trains."[1] By WILLIAM HENRY PREECE, Assoc. Inst. C.E.

IN the two Papers on "Railway Accidents" by Mr. Brunlees (M. Inst. C.E.) and by Captain Galton (Assoc. Inst. C.E.), read at the Institution during the last session, it was deduced from statistical tables, that the great majority of accidents were attributable to preventible causes, and that of these, 27 per cent. were due to the absence of the Electric Telegraph. No description was however given of, nor was any opinion expressed upon, the various methods and mechanical arrangements in use on different lines for supplying this desideratum. The present Paper is intended to furnish this information, and in it to examine the several systems of telegraphic signalling instruments, hitherto adopted in working trains through long tunnels, over steep inclines, at junctions, on single lines, and in other exceptional cases, with particular reference to their liability of error and imperfect construction.

It has been asserted that the Authors previously referred to should have given a list of those accidents which were ascribable to the presence of the Electric Telegraph, as well as of those consequent upon its absence; for it is argued that, while in some instances it may have prevented accidents, yet in other cases it actually produced them. Several examples could be cited, where accidents have resulted from errors, or mistakes in the transmission of messages, or from misunderstanding and mismanagement in the working of the telegraph. Some Railway Companies have from such causes even abandoned its use, after it has once been fixed. The Clayton Tunnel accident would, in all probability, not have occurred, if there had not been a telegraph at that particular spot. This, however, cannot be considered as any argument against its employment in such localities. It might as well be contended that because a distant signal failed, distant signals should be abandoned. The accident in question was not owing to the existence of the telegraph, but to the inefficient regulations adopted in working it. It is only a proof of an incomplete and inadequate system. An accident involving the death of a passenger produces intense sensation. The strictest inquiry is made into every detail. The telegraph, the staff, the rolling stock, the permanent way, are all in their turn severely criticised, and often censured. But the innumerable hair-breadth escapes, where such disasters have been avoided, flow silently by, unheeded and unknown.

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[1] The discussion upon this Paper extended over portions of four evenings, but an abstract of the whole is given consecutively.

Many illustrations could be adduced of accidents prevented by the use of the telegraph, affording indisputable evidence of its utility when well-regulated. Captain Tyler, in his Report on the Clayton Tunnel accident, says:[1]—

> "On the Great Northern Railway, the leading axle of the engine gave way, as the Scotch express train was entering the Tottenham Tunnel on its way to London, on the 27th July 1860, while the train was travelling at a speed of perhaps 60 miles an hour. The engine swerved first to the right, to the down line of rails, and then, after throwing off its left leading wheel, back again to the up line, on which it had been travelling; and it pulled up, in 400 yards or so, with its train across both lines of rails. None of the passengers were hurt, and no one suffered but the fireman, whose thumb and finger were crushed between the hand rail of the engine and the side of the tunnel, as he held on to the former; and it was to the circumstance that the engine thus grazed, and received support from the wall of the tunnel, that the fortunate escape of the passengers was under Providence due. But it was in the neighbourhood of this tunnel that the two Scotch express trains, when they were in time, usually passed each other, the one being due to reach King's Cross at 9.30 P.M., the other to leave it at 9.50 P.M. Happily, the down train was somewhat delayed in starting, by the number of people who presented themselves to travel by it, and the tunnel was comprised in a section of line worked by telegraph. The signalman south of the tunnel received notice from the signalman north of the tunnel of the up train having passed him; and he was made aware of its having entered the tunnel shortly afterwards by hearing a bell ring outside of his hut, connected with a signal north of the tunnel, similar to that at the south end of the Clayton tunnel to which I have had occasion to refer. He observed that it was longer than usual in coming to him, and heard a good deal of whistling from the engine. He found that his telegraph would not work to the northward, and he received notice of the approach of the down train. He therefore took upon himself the responsibility of keeping up his signals against that train, under the apprehension that there might be something wrong in the tunnel; and he thus prevented what might have been a most serious accident, as may be

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[1] *Vide* 'Reports of the Inspecting Officers of the Railway Department, &c., upon certain Accidents which have occurred upon Railways during the year 1861." Folio. Lond., 1862. Page 93.

imagined, when I add, that eight hours were afterwards occupied in clearing the down line before the train for the north could proceed on its journey."

On the other hand, Captain Tyler, in the same Report, says:[1]—

> "On the Great Northern Railway, on the 14th December 1853, three trains were passing through the Stoke Tunnel, half a mile long, between Corby and Great Ponton. The gradient was a descending one of 1 in 180, and the trains left Corby, which is eight miles to the south of Grantham, at 12·30, 12·35, and 12·45, respectively. The driver of the second of these trains slackened speed very properly, in order to avoid collision with the first; but in endeavouring to prevent one accident he occasioned another, for the third train caught up the second train, and came into collision with it, when it had proceeded about two-thirds through the tunnel, and the guard of the second,—a coal train, was seriously injured.
>
> "In my report of the 3rd January 1854, upon that accident, I was led to state prematurely that I was happy to learn that the tunnel was about to be worked by telegraph, no train being permitted to enter at one end of it until the preceding train had passed out at the other end. This was not adopted sufficiently soon for the exigencies of the case; for within three months afterwards another collision occurred, under precisely similar circumstances, on the 7th March, 1854. Three other trains left Corby for Grantham at 9·36, 9·45, and 10 A.M. The driver of the second train was proceeding cautiously through the tunnel, at a speed of about 14 miles an hour, that he might not run against the first train, and he also was caught up by the third train. After the second collision the tunnel was supplied with a telegraph."

Experience has therefore proved, that there are localities where the adoption of the telegraph for signalling trains is essential. The Author would refer to such places as the Victoria Station, Pimlico; the New Street Station, Birmingham; the Lickey Incline; and the Box, Kilsby, and Stoke Tunnels. But it must not be inferred that, because telegraphs are sanctioned and are used in similar situations, the Author advocates the general and indiscriminate application of the Electric Telegraph, as a primary power, in the working of railways. On the contrary, he does not hesitate to affirm, that the greatest caution should be exercised in its introduction. It should never be employed until its use is imperatively demanded, for the most perfect telegraph is liable to occasional accident and interruption. It is, at the best, like many mechanical arrangements, an uncertain agent. Its defects and probabilities of failure have apparently been reduced to a minimum, but still, implicit reliance cannot always be placed upon its efficiency.

The chief advantage of the Electric Telegraph lies in its secondary, or auxiliary character. In this capacity it is an invaluable agent in the hands of a traffic manager, and no railway should be without it, while upon single lines it is absolutely essential. It hastens the transaction of business, instils order and regularity into the running of the trains, and produces punctuality, which is the greatest element of safety in the working of a railway. In moments of emergency, when trains break down and accidents arise, despatch is everything, and the importance of the telegraph is then evident. It fortunately happens that accidents which affect trains very rarely injure the telegraph, and being chiefly required in such urgent cases, it is generally available, and its services are correctly appreciated. But accidents are comparatively few and far between, and a well-regulated telegraph is frequently allowed to fall into disuse. Railway Directors, after a serious accident, are liberal enough in their allowances for telegraphs, and other elements of safety; but long immunity from accident lessens their vigilance, economy prevails, the staff is reduced, and the system again becomes loose and irregular.

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[1] *Vide* Ibid. Page 91.

The maintenance of an efficient telegraph is undoubtedly costly. Its debits are only too visible—its credits are unknown. But how trifling is its cost when compared with that of a single accident! Its erection is cheaper than that of the fencing of the line. To quote the words of Captain Huish, as reported by Mr. Edwin Clark,[1] "If only one collision of a Passenger Train, with its sickening accompaniments of suffering, to say nothing of its heavy expense, were prevented by a free use of the Telegraph, the immunity would be cheaply attained, and the cost of the improvement be amply compensated."

The question has frequently been mooted, as to the advantage of dividing lines into sections, and of maintaining trains a certain distance apart, in place of separating them by intervals of time, as at present. The Author does not propose to discuss this broad question. He will only allude to it incidentally, and leave it for subsequent discussion. It is one more suited for the Railway Manager than the Telegraph Engineer.

Mr. Cooke, the original introducer of the Electric Telegraph into practical use for commercial operations, was also the first to point out its adaptability for railway purposes. He published an interesting pamphlet in 1842, called "Telegraphic Railways,"[2] in which he suggested the principle of working which has been more or less followed in every system that has been subsequently introduced; most of the railway signalling telegraphs being merely mechanical improvements upon Mr. Cooke's idea. He conceived a line of railway divided into sections, each of which should be governed by its own telegraph, and into which no second train should be allowed to enter, until the first had been signalled clear of it. Thus trains, in place of being maintained at a certain presumed safe distance apart by intervals of time, would be kept secure by being divided by an interval of space, which is pronounced by many to be a more satisfactory principle than that almost universally adopted. It is argued, that where fast express and slow goods trains are travelling over the same line, now through a thick fog, now up a wet incline, it is nearly impracticable to maintain that rigid interval of time which is essential to prevent collision; but when two trains, however rapidly, or slowly they may be running, are invariably kept apart by an interval of two, three, or four miles, such accidents are impossible. This Mr. Cooke essayed to obtain by what has since been termed the 'block' system.

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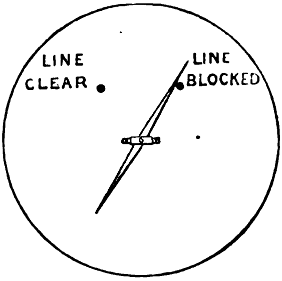
[1] *Vide* "Letter to Captain Huish, as to proposed improvements in the Electric Telegraph system, for the service of the London and North-Western Railway Company. By Edwin Clark. March 1854." 8vo. Lond. Page 12.

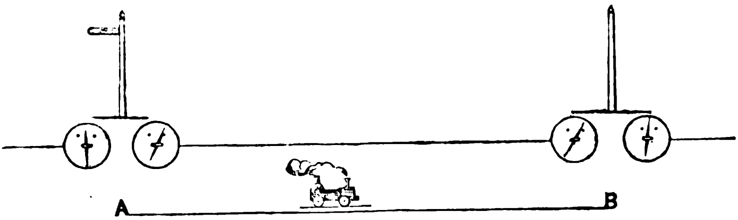
[2] *Vide* "Telegraphic Railways; or, the single way recommended by safety, economy, and efficiency, under the safeguard and control of the Electric Telegraph. By W. F. Cooke." 8vo. Plates. Lond. 1842.

Fig. 1.



The line being divided into sections, each having its own telegraph, every instrument should declare upon its face, whether there was a train upon that length, or not. The needle instrument which he employed (Fig. 1) had two signals—the one to the left signifying 'line clear,' and the one to the right 'line blocked,' or 'train on line.' Whenever a train entered the length A B (Fig. 2), the man at A would signal 'train on line' to the man at B, which would be acknowledged by him, and be maintained, or 'blocked over' until it arrived at B, when B would remove the block, and signal 'line clear.' The man at A would keep his danger signal on until 'line clear' was signalled, and no second train would be admitted until the first was out of that length. When 'line clear' was given, he would acknowledge that information, and take down his danger signal. The out-door signal at A would, therefore, be a repre-

Fig. 2.

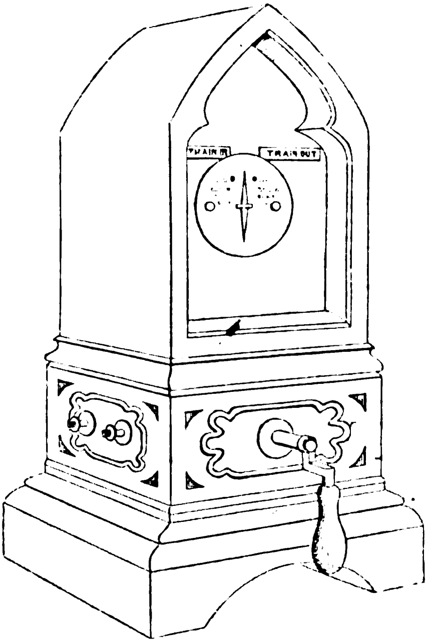


sentation of the instrument at B, and become practically a distant signal worked by B; and this, in the Author's opinion, is the principle upon which all telegraphic railway signals should be constructed. It is impossible by mechanical means to work distant signals much beyond 1,000 yards, but by this plan the distance can be increased ad infinitum. It is evident that, whether the telegraph be general, and the line divided into sections, or whether it be local, and only applicable to a tunnel, or an incline, the principle is the same.

This complete system of Mr. Cooke's has been much overlooked. It was established in 1844, on the Eastern Counties line, between Norwich and Yarmouth. But each station contained as many needles as there were stations (five in all) on the line, and thus the position and the progress of every train could be perceived at any moment. It was abandoned for a less elaborate system, in consequence of the expenditure entailed in the maintenance of so many wires and instruments.

Most railway companies, in working their long tunnels, &c., employ simply a single-needle speaking instrument, which by a momentary deflection on one side, or the other, gives the information of the entry, or exit of a train. Figure 3 shows the instru-

Fig. 3.



Single-needle Instrument.

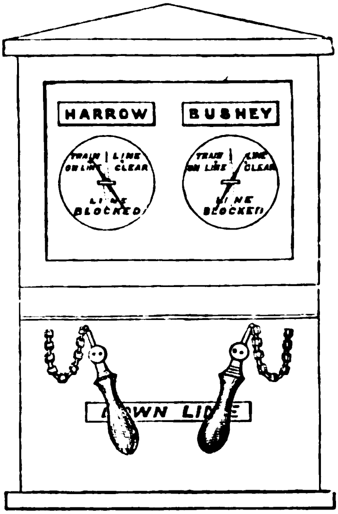
ment most generally employed;—one beat to the right signifies 'train out,' one to the left 'train in.' It is used indiscriminately for both the up and the down lines.

When a train enters a tunnel, the signalman, at the end from which it proceeds, telegraphs to the man at the opposite end 'train in'; and when it arrives at that end, the man there signals back 'train out.' The danger signal is raised while the train remains in the tunnel, and a second one is not allowed to enter until the first has been signalled out. This is a simple but faulty system. It is that which was used at the Clayton Tunnel, and perhaps nine-tenths of the tunnels possessing telegraphs are worked on this principle. Economy probably led to its adoption; but it is to be hoped that another such accident as that which happened on the Brighton line will not ensue, to point out to Railway Companies the danger of using such an indifferent system, when much more perfect arrangements are at their disposal. Even as recently as June last, an accident occurred on the London, Chatham, and Dover line, at the Chatham Tunnel, from the use of a somewhat similar plan.

It might be considered, that the simple information of the presence of a train in a tunnel was sufficient to enable a signalman to work his signals, and to prevent the entrance of a second train upon the same set of rails. But when two or three trains are approaching upon different lines at the same time, it is almost impossible for a signalman to retain in his mind the information conveyed by the momentary movement of a slight delicate needle. Perhaps another train enters the tunnel at the other end, and is signalled at the same time. It arrives, is signalled out, and another is signalled in before the first is out. The signalman gets confused, he has recourse to conversation, and admits a second train while the first is still in the tunnel. An accident occurs, with all its sickening horrors and lamentable results. This cheap and inefficient telegraph is then discarded, and a more improved system adopted. But other companies retain the old system until another accident teaches them the same dearly-bought experience. The excuse is, that it has always answered its purpose, and has hitherto done its duty well. The Clayton Tunnel telegraph worked satisfactorily for ten years, but it failed at last.

The needle system was considerably improved by Mr. Edwin Clark (M. Inst. C.E.) upon the London and North-Western line. He perfected the original scheme of Mr. Cooke. Each set of rails has its own independent telegraph for regulating the outdoor semaphore, which thus becomes a distant signal worked by telegraph. Mr. Cooke's double-needle instrument is employed, in which a deflection on one side signifies 'train on line', and on the other 'line clear'; but it is also made to indicate the occurrence of an accident, and that the line is impassable. A bell or alarum upon an independent wire is used to attract attention. Constant currents of electricity are maintained on the wires by pegging the handles over, as shown in Fig. 4, so as to keep one or other of the signals 'train on line,' or 'line clear,' constantly visible; but if the current is cut off, the needle becomes vertical, and produces a third signal. This third signal signifies 'line blocked and impassable,' that an accident has occurred, or that the telegraph is out of order. It is produced either by an accident to the wires, or by severing a small wire, that descends every alternate pole on the line, within reach of the guard or driver of the broken-down train. Thus when a break-down takes place, instant warning of danger is given to the stations on both sides of the disabled train. This is an ingenious contrivance, but it is questionable whether there be any advantage in its adoption. Captain Tyler recommends it in his Report on the Clayton Tunnel accident; but it is believed that the London and North-Western Company have abandoned it in their recent extensions. The non-arrival of the train, and the absence of the proper signal at the proper time, acquaint both the signalmen that something is wrong. The rupturing of this wire only gives them the information a little earlier. The guards, who are allowed to cut the wires, either forget, or omit to reconnect them, and in practice the telegraph is rendered useless until the proper man is sent to repair the mischief. Moreover, these disconnecting points cause many interruptions to the working of the circuit, and their original construction is costly. Everything offering the slightest probability of accident to an electrical circuit should be carefully avoided, particularly when it forms part of such a guardian of safety as a signalling telegraph. The London and North-Western Railway, between London and Rugby, is divided into sections, averaging a little more than two miles in length. This is sufficiently close to avoid the necessity of these dangerous disconnecting wires.

Fig. 4.



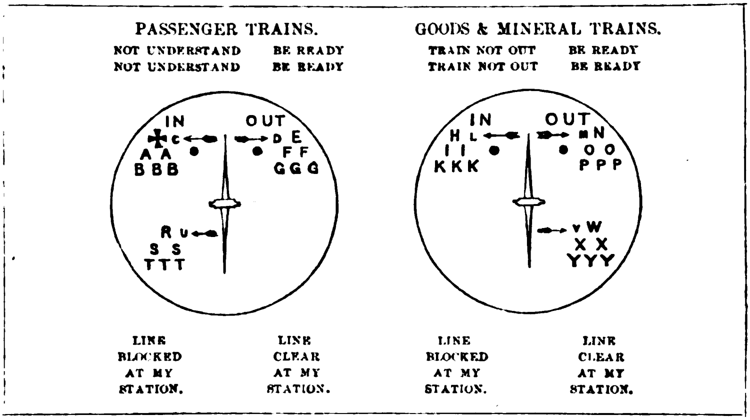
London and North-Western System.

It must be observed, that in working this system on the London and North-Western Railway, that Company do not strictly adhere to what is termed the 'block' system. They allow two, three, and sometimes four trains to be on the same length at the same time, excepting in the case of tunnels. The signal 'train on line' is simply received as a cautionary signal. The vertical needle alone is accepted as the danger signal. This adulterated form of the 'block' system is not sufficient under all circumstances to prevent collision. An accident which occurred near Wolverton on the 22nd February last will demonstrate this in a most striking manner. A goods train passed Hanslope signal hut, and was duly telegraphed to Wolverton; 'line blocked' was given, and the semaphore was raised to 'danger.' A cattle train immediately followed; and, seeing by the semaphore that a train was on the line before him, the engine-driver slackened speed. A coal train succeeded, the line being still blocked, and received a similar caution. When the second train was close to Wolverton, the third train ran into it, killed one man, injured several, and produced considerable damage. The second train was running too slow, the third too fast.

There are evidently great and serious objections to the working of railways upon the space, or 'block,' in preference to the time system. The London and North-Western, the Great Northern, and other Railway Companies have been compelled to abandon it. The telegraph becomes simply the medium of warning and caution, excepting in the case of long tunnels and steep inclines. It enables all slow trains, or trains behind their time to hasten on, because they are made acquainted with clear lengths before them; while all fast trains, or trains before their time, are informed that there is a train in front of them, and are delayed without being actually stopped. The system in use on the London and North-Western line is undoubtedly a wise precaution against accident, but it is by no means a certain element of safety from collision. Were it strictly carried out, as originally contemplated, it would undoubtedly be so. The Company believe that the line cannot be worked if a distance of two miles is invariably maintained between the trains; but if two miles is impossible, why not adopt a shorter length? And if that be not practicable, then a third set of rails is imperative.

A somewhat similar, but much inferior, system is adopted on the Great Northern Railway. The two needles in each direction are used promiscuously for the up and the down lines. Fig. 5 (page 12) will indicate the signals used. Those on the left-hand needle refer to passenger trains; those on the right hand to engines, and goods, cattle, and ballast trains. One beat to the left on either needle signifies 'train in,' one to the right 'train out.' The signals 'line blocked,' and 'line clear,' are given by holding both needles over momentarily to those words. No permanent signals are adopted. Every signal is however registered in a record book, so that mistakes and errors in the nature of the signals sent are carefully obviated. An additional warning-signal is also transmitted to the station at the end of the section in advance of that upon which the train is running, to signify that a train may be expected and attention maintained. This is done by pointing the proper needle twice to the right.

Fig. 5.


PASSENGER TRAINS.
NOT UNDERSTAND
NOT UNDERSTAND
BE READY
BE READY
IN
OUT
C
D E
A A
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B B B
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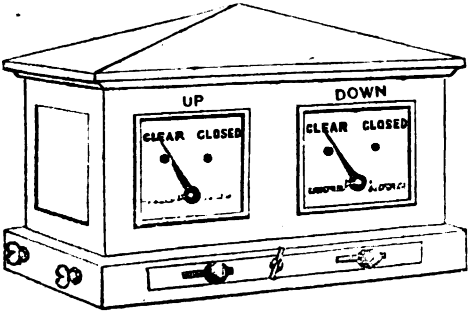
S S
T T T
LINE BLOCKED AT MY STATION.
LINE CLEAR AT MY STATION.
GOODS & MINERAL TRAINS.
TRAIN NOT OUT
TRAIN NOT OUT
BE READY
BE READY
IN
OUT
H L
M N
I I
O O
K K K
P P P
V W
X X
Y Y Y
LINE BLOCKED AT MY STATION.
LINE CLEAR AT MY STATION.

Great Northern System.

The instrument employed on the London and North-Western, the Great Northern, and indeed, that most generally used for railway signalling purposes, is the needle telegraph. Its signals, except in the case of the 'block' system, are transitory, and therefore dependent upon the memory. They are liable to be reversed by the action of lightning, and 'line clear' may sometimes represent 'train on line,' and 'train in' may mean 'train out.' It is moreover capable of being used as a medium of conversation, which is by some considered objectionable in a telegraph employed solely for the regulation of trains. If it is required for conversational purposes, which, in the Author's opinion, is a questionable practice, although recommended by the Government Inspectors, a separate wire should be erected for that object; but that employed to regulate the distant signals should never be used for anything else. The Clayton Tunnel accident is a remarkable instance of the danger of conversing upon the signalling telegraph. Confusion arose, and the accident ensued. The same confusion might have arisen if a separate wire had been employed. On the other hand, speaking telegraphs are unquestionably of service at times. An instance of their value was shown on the London and North-Western line in June 1860. The driver of a goods train stopped at Wolverton, and told the signalman there he was afraid something was wrong with the line near Roade. A message was instantly sent to Hanslope, from thence to Ashton bank, and from there to Roade. The line was examined, a rail was found to be displaced, and the mail train was stopped just in time to save, probably, a disastrous accident. All this was effected in ten minutes. It may be added, that the men were self-instructed in the knowledge of telegraphing, as the use of this instrument for speaking purposes was not contemplated; indeed, it was forbidden. In a system like that on the London and North-Western line, the Author would prefer a separate speaking telegraph connecting several signal boxes in one circuit, and totally distinct from the signalling instruments.

The objections to the needle telegraph, as regards its transitory signals, its liability to reversal and demagnetisation by lightning, and its convenience for conversational purposes, are partially avoided in Mr. Bartholomew's and Mr. Tyer's (Assoc. Inst. C.E.) systems. Mr. Bartholomew's (Fig. 6) is employed on the London, Brighton, and South Coast Railway; Mr. Tyer's (Fig. 7, page 178) on the North London, South-Eastern, and several other lines. Every instrument has an indicator for each set of rails, with two signals, the one signifying, 'line clear,' the other 'train on line.' Tyer's instrument has separate indicators for those signals which are sent and for those which are received. The signalman can see by the upper indicator the last signal received at his station, and by the lower one the last signal transmitted. The indications of both these instruments are constant, and can, therefore, as in Mr. Clark's, be referred to at any moment. This constant deflection is maintained in Bartholomew's, by gravity—in Tyer's, by

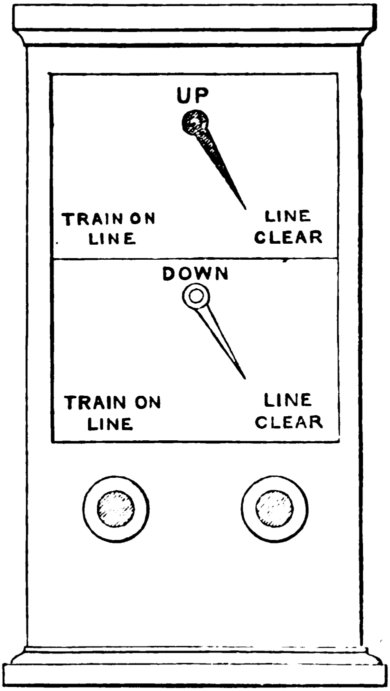
Fig. 6.



Mr Bartholomew's System.

permanent magnetism. In Tyer's instrument the signal at one station can only be altered and maintained by the man at the distant station. In Bartholomew's this property is wanting. Tyer's system has been highly eulogised by the Board of Trade. Both are supplied with bells, or gongs, so that attention is always attracted by sound to the transmission of any signal. In Bartholomew's the down line bell is of a different note to that of the up line. In Tyer's a gong is used for the one and a bell for the other. A code of signals is adopted, by which a varying number of beats on the bell conveys certain information. Thus :—

Fig. 7.



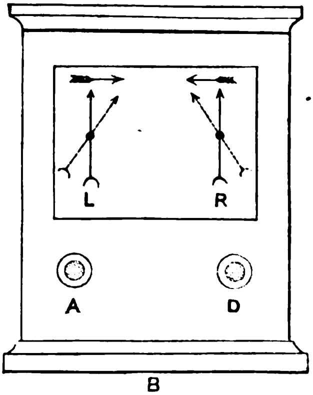
Mr. Tyer's System.

Acknowledgment . . .	1 beat
Passenger Train . . .	2 „
Goods do.	3 „
Express, or Engine . .	4 „
Obstruction on Line . .	5 „
Testing Signal . . .	6 „

Both instruments are worked on precisely the same plan as the block system, viz: as though they were distant signals. No train is allowed to enter a length unless the index shows 'line clear.' If clear it is signalled on the bell, is allowed to proceed, and the index is thrown over against the admission of any succeeding train.

On other lines systems are at work which differ in some respects from those already described. On the South-Eastern Railway Mr. C. V. Walker has established a system of signalling by bells alone, with a code somewhat similar to that adopted by Mr. Tyer. He dispenses entirely with any index, and depends solely upon the information conveyed by the sound of the bell. It is used principally to give warning of the approach of trains; and not, as in the 'block' system, to regulate the signals. Every train is signalled 'out,' and 'in.' The bells are so connected, that they can be sounded from any point of the line, and thus information of an accident is at once transmitted to the stations on each side. It must be stated in justice to Mr. Walker, that his system was perfect, and in use, long before the introduction of either Mr. Tyer's, or Mr. Bartholomew's, and if the indicating apparatus be removed from them, Mr. Walker's plan remains.

Fig. 8.



Regnault's System, Western Railway of France.

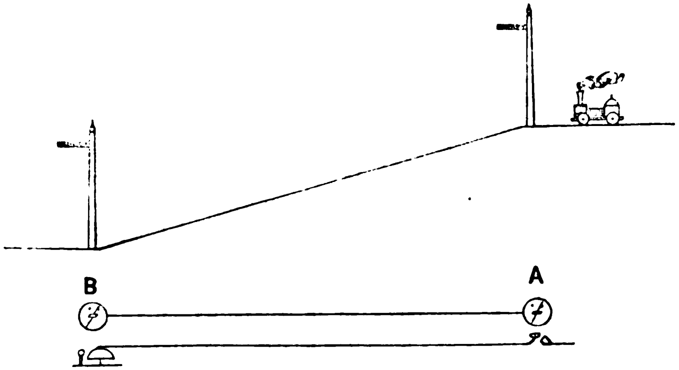
In France a method of signalling (Fig. 8) is employed, which does not differ essentially from the 'block' system previously described. It is the invention of M. Regnault of the Western Railway. Bells are not used. The needles have only one deflection, in the direction shown. The vertical position indicates 'line clear,' when deflected 'train on line.' The needle L denotes a train departing from A; R, one arriving from B. L is called the 'repeating' and R the 'indicating' needle. When a train proceeds from A to B, the man at A presses the key D, which transmits a current to B, and deflects the needle L as shown. The needle remains deflected, as in Tyer's instrument, by the action of a permanent magnet. It also, by an ingenious contrivance, brings the battery into play at B, and sends a current back to A, which constantly deflects the needle L; thus blocking the needle over by a self-acting arrangement, and not by hand as in Clark's. The current flows until the arrival of the train at B, when the needle at B is restored to its normal position by the pressure of the key A, the current being removed, and the needle at A restored to 'line clear.' This instrument has many defects which render it inferior to those in use in England. The plan of blocking over by self-adjusting mechanism is highly objectionable, besides which, the signals are completely under the control of either man. In the English 'block' systems, the signal at one station can only be altered by the man at the other; but in this instrument 'train on line,' and 'line clear,' can easily be substituted without the possibility of detection. The French use also, on some lines, an instrument fixed permanently, at distances of about two miles apart, by which an alarum is sounded at each station on both sides when accidents occur. They are called 'appareils de demande de secours.'

In Germany, where the trains are few and far between, and where level crossings are numerous, bells are fixed along the line at short intervals. All the bells between two stations are rung simultaneously on the departure of every train from one station to another. They act simply as a warning to gatekeepers, signalmen, and platelayers. Such a plan is evidently impracticable in England.

It must be observed that in all these systems, the two signals, denoting such different meanings—the one the element of safety, the other the source of danger,—are not sufficiently distinct in their opposite indications. On the line, the semaphore arm, at one time elevated, and at another depressed, is unmistakeable in either position. So with a disc, at one time visible, at the next moment obscured, no error can occur. But a thin index, in a dark, dismal hut, with only a slight movement from one side to the other, whether it be momentary, or permanent in its deflection, is not decided enough to avoid misconstruction, when examined hastily. In electric, as in out-door signals, nothing should be left in doubt, or to chance. The two opposite signals should be perfectly distinct. It cannot be said to be so in any one of the instruments that have been described. Mr. Highton, in 1854, endeavoured to obviate this in an instrument which is exhibited, and Mr. Spagnoletti, of the Great Western line, has recently introduced the same method on the Metropolitan Railway. It is a modification of the needle instrument, and is used on the 'block' principle. The front of the dial has a slot about one inch and a half long by one inch wide, which allows one of the signals to be visible. The signals consist of bold printed words—the one 'line clear,' the other 'train on line.' The former is printed on a white, the latter on a red ground. They are so attached to the needle, that when it is deflected to the right, 'line clear' is shown, and when to the left 'train on line.' When no current flows neither is fully visible. Although this is to some extent an improvement upon existing needle instruments, yet it removes none of the objections to that system. The needle is still subject to reversal. One instrument may show 'line clear,' whilst that with which it is in correspondence is signalling 'train on line.' It requires considerable power to work it, and is on that account liable to be deranged.

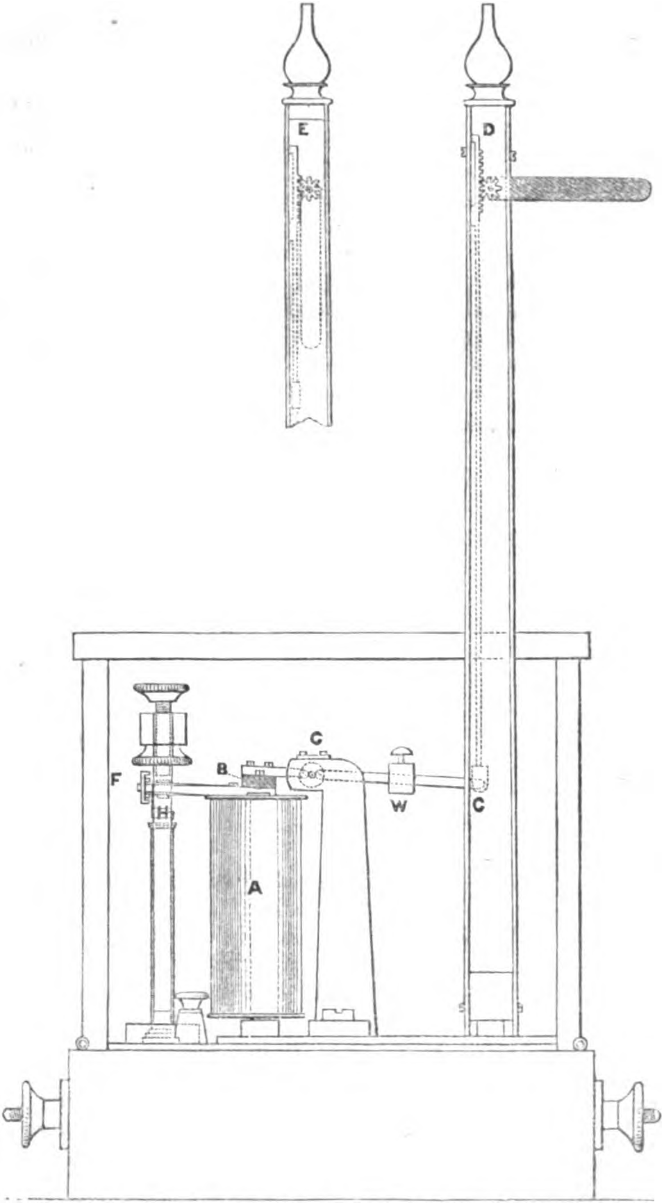
It must also be remarked, that the signals of all these systems are so dissimilar to those used out of doors, that the signalmen have to master and comprehend two different and distinct methods of signalling—the one, line signals, to regulate the trains,—the other electric signals, to regulate those of the line. This with uneducated men, is always a matter of difficulty, and generally results in confusion in moments of danger, when clearness of mind and confidence are essential. There is no reason why electric signals should not correspond precisely to outdoor signals. An electric signalling instrument is for all practical purposes a distant signal worked by electricity. The bell corresponds to the whistle of the engine, the instrument to the distant signal. In Fig. 9, which represents a steep incline, down which no train must go until the first train is signalled clear, the telegraph instrument is always set at 'line blocked,' until it is asked to be taken off by the bell from A. It can only be altered by the man at B. It is therefore a distant signal worked by B. A makes his outdoor signals correspond precisely with those of his instrument; and thus, though A and B may be miles apart, the signals at A are practically under the control of B, and become distant signals worked by him.

Fig. 9.



Now, instead of having a needle instrument like Clark's, or an indicating instrument like Tyer's or Regnault's, the Author employs a system which consists of an exact counterpart, on a small scale, of the signals used on the line, and the instrument for which is worked precisely in a similar manner. If a semaphore be used

Fig. 10.



Mr. Preece's System.

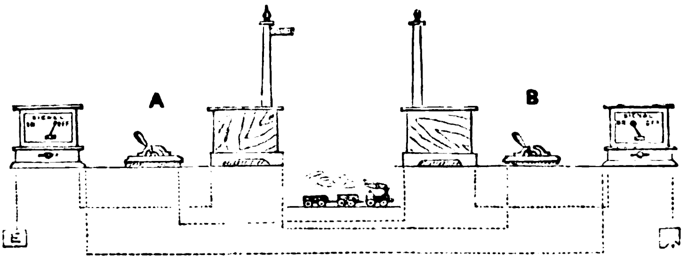
on the line, he employs a miniature semaphore, whose arm is raised and lowered by electrical agency. If a disc, then he has a disc, whose half revolutions are effected by the same power. Whatever signal be adopted on the line the same is represented indoors. Bold unmistakeable signals are thus obtained, whose opposite meanings cannot be misread, and confusion is avoided, not only by their distinctness but by their assimilation to those of the line; whilst confidence is assured by their perfect comprehension by the signalmen, and by their inability to cause misunderstanding. The electric signals are worked on precisely the same plan, and nearly by the same means as the outdoor signals—electric force only being substituted for mechanical power.

Fig. 10 explains the construction of the semaphore. The electro-magnet A, when traversed by an electric current, attracts the armature B. This armature is attached to a lever B C, centered at G, and connected with the rod C D. The movement of this rod, produced by the attraction of the armature B, respectively lowers or raises the semaphore arm E, by means of the rack and pinion movement D. The ascent of the rod is effected by the action of the electric current; its descent, and therefore the elevation of the arm, is maintained by the weight W. Thus, every current of electricity transmitted through the electro-magnet lowers the semaphore arm E, and this arm can be kept in a depressed position as long as a current flows. By a simple alteration of the rack and pinion movement, the attraction of the armature can raise instead of lower the semaphore. But the other construction is preferred, as in the event of any accident, the danger signal is at once exhibited. When at rest the signal is at danger, and it is only when a current is flowing that the 'all-right' signal can be shown. The weight W is adjustable, so that the instrument can be worked with the most delicate currents, and the danger signal is as easily lowered at a hundred miles as at one mile. It also registers its own signals by means of the contact piece at F. Whenever the armature is attracted, the piece F is brought into contact with A, another current is transmitted on the wire, which rings a bell and indicates that the signal is on, or off, as the case may be. This is also shown by an index on the bell. (Fig. 11, page 184.) The 'all-right' signal being maintained by a constant current, should an accident arise either to the train, or to the wire, the danger signal is immediately shown.

In every respect this system is worked like either of the 'block' systems, excepting that in place of having an indicator pointing to 'line clear' or 'line blocked,' an 'all-right' or 'danger' signal is shown, corresponding to the signals used out of doors. It may be remarked that the machinery is of the most simple character, almost incapable of derangement, and, if deranged, reparable by an uneducated pointsman. The signals are unmistakeable; indeed it seems evident, that if a system of signalling is found sufficient to work the trains by manual power, that same system must be equally efficient when manipulated by electrical agency.

The manner in which a tunnel, or a section of line would be worked is seen in Fig. 11. A train has just proceeded from A to B. A signals 'train in' on the bell. B replies by raising the semaphore at A, and he maintains it in that position until the train arrives, when he lowers it again. A raises his outdoor semaphore, at the same time making it correspond exactly with his indoor instrument. While the semaphore is raised no second train can be admitted. The index on the bell at B shows the condition of the semaphore at A, so that the signalman has a perfect knowledge of what he is doing. It will be perceived that this is worked precisely as if it were a distant signal. The bell, like the whistle of the engine, gives warning of the approach of a train; the key, like the lever handle, raises the signal; the indicator, like a signal within view, shows that it has acted properly. Everything is within the control of the signalman. If an accident occurs, either to a train, or by the breaking of the wires, the danger signal is shown at once on both sides; everything is stopped and security is obtained.

Fig. 11.



This instrument has been in use since March last, in working the trains on the London and South-Western Railway, on the incline between the Queen Street and the St. David's Stations, Exeter. It has never once failed. The outdoor signals, on the contrary, have received frequent attention, and the speaking needle telegraph between the same points has been demagnetised and disordered on more than one occasion. It is now in use at several other points, and affords great satisfaction.

The different systems which have been described may here be advantageously compared and their relative superiority discussed.

It will be sufficient for the purpose to confine this to the London and North-Western, Mr. Tyer's, and the London and South-Western systems. Every other is a modification of one of these.

Mr. Edwin Clark (M. Inst. C.E.), in an interesting report, addressed to the London and North-Western Railway Company upon improvements in their telegraphic system, remarked:[1]—

"The following conditions should, I think, be insisted upon in any application of a Telegraph to Railway purposes:—

"1st. The machinery employed must be of the most simple and evident description, not liable to derangement, and easily repaired.

"2nd. The Signals must be simple and few, and so distinctive that no mistakes can occur.

"3rd. No dependence must be necessarily placed on the memory of the person in charge, and the Signals should be permanent and not temporary, or liable to misconstruction or neglect from the absence of the attendant.

"Lastly, and more particularly, no accident should be actually caused by the derangement of the apparatus, or the absence of the Signal-man, but such absence or derangement should merely cause the delay of a Train."

In the first place, the needle instrument is unquestionably of the simplest and most evident description, but it is liable to derangement. Lightning, the great enemy of telegraphs, soon puts it 'hors de combat;' and though it is without difficulty remagnetised, still in the hands of rough men its delicate pivots and weak axles are easily injured.

Tyer's instrument is very simple in construction; but being kept under lock and key, no derangement can be remedied by the man in charge, and a new instrument, or the proper man, must arrive before it is again serviceable. If one needle of Clark's instrument breaks down, there is another to continue the work; but if Tyer's fails, as it is only worked on one wire, no resource is left but the ordinary time-tables. A system worked on one wire, on the score of economy, may be desirable, but on that of efficiency, it is disadvantageous. Moreover, Tyer's instrument is affected by atmospheric electricity—a flash of lightning may make it give a false signal. When 'train on line' should be shown, it may indicate 'line clear.' It can also be demagnetised and rendered useless. If a wire breaks, or an accident occurs, nothing is shown on Tyer's instrument, but Clark's needles at once give their warning sign. For these reasons the Author considers the needle instrument superior to Tyer's. As regards the semaphore, the construction is more complicated than that of either of the others; but it is so evident, so little liable to derangement, and so easily repaired, that it may certainly maintain its place by the side of the needle instrument.

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[1] *Vide* "Letter to Captain Huish, &c." Page 17.

Secondly, as respects the signals being simple and few, and so distinctive that no mistake can occur, it is hardly necessary to refer to this particular characteristic of the semaphore.

Thirdly, in neither instrument is any dependence placed upon the memory of the person in charge. The signals are permanent, and not temporary. This permanence is maintained in the semaphore and needle instruments by continuous currents, which are liable at any moment to be interrupted by an accident to the wires, or by the break-down of a train. These two instruments therefore fulfil, in the highest degree, Mr. Clark's last and important condition—that "no accident should be actually caused by the derangement of the apparatus, or the absence of the signalman, but that such absence or derangement should merely cause the delay of a train." By the use of continuous currents instant information is at once transmitted to both ends of the line of any accident to the train, or to the wires, an advantage which Tyer's instrument does not possess, and which alone, independent of its construction, places it below either the semaphore or the needle in point of efficiency. Any system worked by momentary currents upon a single wire must fail to meet this most important condition, and no experienced telegraphist would recommend to any Railway Company, the adoption of a system which is based upon such an erroneous principle. Where permanent currents are employed, it is impossible to transmit false signals; but where momentary currents are used, such false signals are not only possible but frequent. On the North Kent line, where Mr. Tyer's instrument is in use, more than one accident has occurred from this cause. There is not any record of such accidents where permanent currents are employed.

Signor Vincenzi, an officer in the Italian army, had an ingenious contrivance in the International Exhibition, whereby trains in motion might receive and send signals of their approach to stations and trains on the same section of line. Similar self-acting mechanical arrangements have often been suggested, and numerous patents have been taken out, for engines to receive and send signals—for trains to communicate with each other, and to act upon signals—for signals to register themselves on engines and at stations; and, indeed, for every conceivable purpose of giving information and obtaining assistance. But as Mr. Edwin Clark, in the report previously alluded to, very properly observes,[1]

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[1] *Vide* Ibid. Page 6.

"All the arrangements that have been thus proposed have emanated with a good motive from very ingenious individuals, but they have invariably been from persons who have had no practical experience in the difficulties and intricacies of an actual Telegraph." The Author is not aware of any such single self-acting arrangement having been carried into effect, and been proved to be practically useful.

The application of the telegraph to the working of single lines is a subject which demands great attention from railway managers. Where more than one engine is employed, the use of the telegraph is rendered compulsory by the Board of Trade. There are two ways in which this may be done; either in a primary manner, to rule and regulate the signals of the various stations on the line, by one of the signalling systems previously described, or in a secondary manner, to give notice of the delay of trains, to hurry on one train, to stop another, to alter the authorized passing places, and to prevent the unpunctuality of one train from affecting all the rest. Some single lines are worked on the blocked needle principle, and others with Tyer's instrument. Some are worked on the 'train staff' and 'ticket' system, many by the time-tables alone, the passing places of trains in such cases being altered by some authorized officer by means of the telegraph. The 'train staff' is a sort of truncheon, made of different sizes, forms, and colours; sometimes supplied to the guard, sometimes placed in a socket on the engine, or tender. Each section of line has one apportioned to it, different and distinct from every other. No train is allowed to travel over that section without its staff. "During the operation of ballasting, or when an accident happens, the 'staff' is supreme. It must be sent for an assisting engine, or must accompany the ballast engine; and no officer or person in authority can send forward an engine or train during its absence; but the most hurried director, or the most impatient manager must, as well as a third-class passenger, await its return."[1] With such systems in use collisions are almost impossible. The 'staff' has to be obeyed, or time-tables adhered to, and accidents become unknown.

If punctuality is obtained, everything goes well. But delays arise from many different causes, and the delay of one train throws all the rest into irregularity. The telegraph now becomes available to restore order. Two trains (Fig. 12, page 188) are appointed to meet at B. That coming from A is punctual, that from E is late. It is found that the former can be sent on to C before, or by the time the latter arrives there. C is therefore made the crossing point in place of B, but several precautions have to be adopted in carrying this into effect. There must be no mistake in the instructions given. The station-masters, guards, and drivers must all have explicit orders, and the superintendent must know that they have these instructions correctly.

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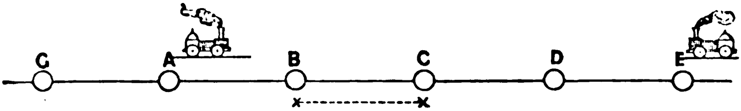
[1] *Vide* "The Quarterly Review," 1862. Vol. 111, page 17.

Fig. 12.



On the Shrewsbury and Hereford Railway, a collision with loss of life occurred, in a case of this sort, from the insertion of the word "at" in the copy of a telegram, and from the general want of explicitness in the wording of the message itself. On a railway in the north of Scotland the superintendent was himself killed in a collision caused by his own irregular orders. Everything depends upon the correctness of the message.

On the London and South-Western Railway the system employed is as follows:—Each single line is divided into districts of about fifty miles in length. Over each district there is a superintendent, who has the control of the traffic upon that length. Every train on its departure from certain fixed stations is telegraphed to the superintendent, who thus knows precisely how the trains are running. If a case occurs, as shown in Fig. 12, he takes his measures accordingly.

1st. A message* is sent to C, ordering the stoppage of the up train until the arrival of the down train at that station.

2nd. This is repeated in slightly different language by the station-master at C.

3rd. Another message is sent to B, to send on the down train to C, and to pass the up train there.

4th. This is also repeated in a similar manner to the previous message.

5th. The engine-driver of the down train, if an express, is warned at his last stopping station that he will have to stop at C.

Written orders are given to the driver, with a copy of the message itself. No error, or misunderstanding can arise, except from the wilful disregard of clear and explicit instructions: nothing is left to chance. A regular form is adopted for wording these messages, and different-coloured message-papers are used for the various orders issued. Those respecting the stopping of trains are coloured red; those relating to the forwarding on of trains are green. It will be seen that each alteration of a passing place involves four separate messages—in the case of an express-train five—each message being repeated to insure correctness. It is found in practice, that all this is accomplished in a period averaging five minutes. The greatest care is taken that everything shall be written down. Indeed a message should never be sent by telegraph unless it has been first recorded on a proper form; and it should always be preceded by its proper prefix, denoting its nature and importance.

On the London, Chatham, and Dover Railway, in January 1862, an express train was thrown off the rails near the Rainham station, and considerable damage sustained, though fortunately no lives were lost. This accident might have been avoided if the station-master at Sittingbourne, who had been informed of the fact of there being something wrong by the driver of a previous goods train, had taken the precaution to write down a message, and have it sent with the danger prefix. As it was, he simply told the clerk to warn Rainham of there being something wrong. Another station, seeing conversation going on, broke in with another message, produced delay, and the accident occurred. Most of the delays, and irregularities on railway circuits arise from this simple circumstance. On commercial circuits conversation is strictly prohibited. Everything that is sent, or received, is carefully written down. If Railway Companies carried out the same rule, they would soon reap the benefit in greater despatch of business, prompter attention, and fewer errors. It should also be added, that no message of importance should ever be transmitted by telegraph, without its repetition being demanded, nor should such message be acted upon without such repetition being sent. This is the only safe method to avoid inconvenience from errors, which constantly occur from innumerable causes, even with the best-regulated telegraphs.

On the West Midland, the Shrewsbury and Hereford, and on several other single lines in the west of England, the blocked needle system is carried out. There are two wires—one being used for the 'block,' and the other for speaking purposes. Bells are dispensed with. Explicit instructions are given, so that no train can start until the line is known to be clear; and immediately a train enters a station, the needle is deflected over to 'line blocked.' Record books are carefully kept.

Record books, or slates, in which the times of starting and passing of all trains are entered in ruled columns, are essential elements of attention and regularity. Captain Tyler says,[1]—"A man is obviously less likely to commit an irregularity of any sort in duties of this description, when he is himself compelled to make a permanent record of it, liable at any time to be brought against him, open to observation on periodical, or irregular inspections, and checked by other records made by responsible officers within a short distance, and perhaps on both sides, of him." Such record books should invariably accompany signalling telegraphs. Few lines now omit to avail themselves of their use. They are, however, scarcely necessary, where the electric signals are worked purely as distant line signals.

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[1] *Vide* "Reports of the Inspecting Officers, &c." 1862. Page 90.

In America, where nearly all the railroads are single lines, the traffic is almost entirely worked by telegraph. The system employed is the same as that used on the London and South-Western Railway. Prescott says:[1]—"Engineers and conductors now actually feel safer and more secure while moving under telegraphic orders than when following their printed instructions; although, at the time the system was inaugurated, it was not a little amusing to the operators to witness the alarm manifested by these same men at this innovation upon their old-fogyish views."

There is no question that, if properly worked, single lines would be sufficient to meet a great portion of the requirements of the railway service of this country where double lines at present exist. Mr. Minot, the chief superintendent of one of the best-managed railways in America, the New York and Erie line, says:[2]—"A single-track railroad may be rendered more safe and efficient by a proper use of the telegraph than a double-track railroad without its aid; as the double-track can only obviate collisions which occur between trains moving in opposite directions, while the telegraph may be used effectually in preventing them either from trains moving in an opposite or the same direction." Vast sums of money have been uselessly spent in the construction of double lines in this country, where single lines would meet all the traffic. Parliament has compelled the London and South-Western Railway to double their line from Southampton to Dorchester. A single line would be ample for the traffic of that district. But single lines, until recently, have never been properly worked by telegraph. The telegraph was not understood. No reliable signalling apparatus had been introduced, and delays arose. The public remonstrated, and shareholders' capital has been recklessly expended. With a reliable signalling apparatus to regulate the signals—with a well-managed speaking telegraph to regulate the trains—safety is assured, regularity obtained, and single lines become as secure and rapid as double lines.

Even on double lines the telegraph, properly applied, becomes a great element of safety. As a secondary power, it is invaluable. But railway managers are, to a great extent, prejudiced against its adoption. They do not use it, because they do not, or will not understand it.

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[1] *Vide* "History, Theory, and Practice, of the Electric Telegraph. By G. B. Prescott." 8vo. Boston (U.S.), 1860. Page 235.

[2] *Vide* Ibid. Page 236.

On most railways the telegraph is held in the lowest estimation. Its construction is the very last thing thought of—its convenience is never consulted. Railway managers order a telegraph, and think little more about it. The signals, the switches, the porters' rooms, and the urinals, are all carefully considered; but the telegraph—the most important element of safety—is often neglected to the last moment. It is assumed that it can be fixed anywhere, and that any vacant spot in the parcel, or booking office is sufficient for its purpose. Light is essential to insure attention to its call. Air is imperative to secure the health of the attendant. Indeed special offices should always be constructed at all stations. It is a mistake to combine telegraphing with other occupations. A booking clerk may be attending to passengers when he is urgently wanted at the instrument. A parcels' porter may be absent, when a danger telegram is required to be sent. Constant attention, which is imperative in a well-regulated telegraph, can only be obtained by having a special telegraph-clerk situated in a convenient office, free from interruption, and undisturbed by the ordinary business. The instrument is frequently left in the hands of persons incapable of using it; and it is no uncommon thing to find it placed under the charge of those who, though capable of working it, are, from a superabundance of other employment, unable to give it that strict attention so necessary to make it a valuable and reliable agent.

Captain Tyler says:[1]—"Want of a proper system of working and using the telegraph, combined with the employment of unreliable servants, or of servants with too much of other work to attend to, that has in like manner led to accidents in other cases,—that has induced mistakes on the part of the men which would not otherwise have been made,—that has afforded an excuse for not employing it,—and that has prejudiced railway managers against it, in a way materially to hinder its adoption and retard its progress; while the want of a really efficient code of regulations, ready to be applied, and in which confidence can be placed, has also partly contributed to the same result."

There is no doubt that, indiscriminately used, the telegraph becomes a positive source of danger. Still, carefully applied, it may be made the greatest element of safety. There are localities and occasions where it becomes essential and imperative; and if railway managers will only examine and study its construction and principles, they will find it a power in their hands to produce order and punctuality, security and speed, and, as a necessary consequence, prosperity, and immunity from those dreadful disasters which have startled the public, proved such a serious loss to shareholders, and thrown so many happy families into misery, mourning, and grief.

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[1] *Vide* "Reports of the Inspecting Officers, &c." 1862. Page 92.

The Paper is illustrated by a series of diagrams, from which the woodcuts, (Figs. 1 to 12) have been compiled.

Mr. **Preece** said, in writing this Paper, he had two objects in view—first, to bring before the Institution and the railway world the system of signalling that had been introduced on the London and South-Western Railway; and secondly, to place upon record an account of the various applications of electricity to the signalling and working of trains. The Minutes of Proceedings already contained two communications on the Electric Telegraph,[1] several on Submarine Cables,[2] and one on Electro-Magnetism as a Motive Power;[3] but there was no description of the manner in which electricity had been applied to railway purposes. This he had endeavoured to supply in the present Paper, and he trusted to some extent successfully. The necessity for an opportunity of discussing this subject, and of learning what was being done in this department on different lines, would be apparent, when he mentioned that the practice of the principal Railway Companies did not agree upon this point, no two lines having their termini in London following the same system. For instance, the Great Eastern had a system of their own, based upon the needle instrument; the Great Northern one which was only understood, he thought, by themselves; the London and North-Western used Mr. Clark's plan; whilst the Great Western employed various contrivances, but were now introducing the invention of Mr. Spagnoletti. On the London and South-Western Mr. Preece's system was in operation. The London and Brighton presented the curious anomaly of working one end of their line upon one method, and the other upon a different plan. On the South-Eastern main line bell-signals were adopted; while on one of the branches, the North Kent, Mr. Tyer's instrument was in use. Similarly, the Reports of the Inspecting Officers of the Board of Trade upon Railway Accidents were at variance; for in one report, Captain Tyler, R.E., (Assoc. Inst. C.E.,) recommended to the London and Brighton Company the use of Mr. Tyer's instrument, and in another he advocated the needle system. Colonel Yolland, R.E., was invariably in favour of the needle system. Again, he thought, that if the London and North-Western Company were acquainted with the methods in use on other lines, the tunnel at New Street, Birmingham, would not continue to be worked by a system which required eight wires, whilst the London, Chatham, and Dover Company only employed one wire.

The sources from which he had been able to derive the materials for his Paper were very limited. The only published account, with which he was acquainted, of any system of telegraphic signalling was that given in the careful and elaborate report of Mr. Edwin Clark to the London and North-Western Railway Company.[1] No treatise upon telegraphy contained any detailed statement of what had been accomplished in this special department. He had been obliged, therefore, to resort to the reports—often long and tedious—of the Government Inspectors upon Railway Accidents; and in this way he had waded through upwards of two hundred of those reports, until he was wearied with the same tale of instructions disregarded, precautions neglected, and experience ignored.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xi., pp. 299-388.

[2] *Ibid.* vol. xvi., pp. 188-225; vol. xvii., pp. 221-385; vol. xx., pp. 26-105; and vol. xxi., pp. .

[3] *Ibid.* vol. xvi., pp. 386-421.

In dealing with this subject, he had endeavoured to be impartial. Having an invention of his own, he was, however, naturally inclined to regard it with some affection; but he was sure those gentlemen whose processes had been alluded to, would do him the justice to say, that he had not failed to describe them as accurately as was possible under the circumstances. It might appear somewhat invidious to have selected Mr. Tyer's instrument, and to have brought it into rather unenviable juxtaposition with the needle system and his own. But that was only taken as the best example of a series which he believed to be founded upon a wrong basis,—he meant those methods which were dependent upon one wire and upon momentary currents. In a Paper which was written more for the purpose of provoking discussion than for careful examination, he had been necessarily limited in the description of the various appliances met with on railways. Thus, he had not entered into any particulars about bells; because if he had gone into that subject, a long account would have been required, which would probably not have been generally understood. There were two kinds of bells,—one termed the direct-action bell, the other the alarum. The latter was placed in the box of a pointsman, who had to leave to attend to the points, as the continuous ringing called his attention to the signals. The single-stroke bell was fixed in a box which the signalman never quitted. He had taken an objection to all kinds of self-acting mechanical arrangements, but he excepted the case where distant signals registered themselves. On the London and North-Western line Mr. Whitaker made the distant signal register itself upon the needle. Mr. Preece adopted a similar plan, only in place of the needle, he let the signal repeat itself on a similar signal, but upon a smaller scale.

As regarded the several points to which the discussion might be directed, he would remark that the question which telegraphists were anxious to have settled was, whether lines should be worked by an interval of space, or by an interval of time. The Government

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[1] *Vide* "Letter to Captain Huish, &c."

Inspectors recommended the former; the managers of the principal railways said it could not be done, and that reliance must be placed on the interval of time. As a telegraphist, he did not see why the 'space' system should not be adopted; still he should like to hear the reasons which had induced the London and North-Western Company to modify the original 'block' system. Allusion had been made to the system of signalling on the London and South-Western for working single lines. Of all that he had seen he considered it was the best. It originated with Mr. Williams, on the Yeovil and Exeter line, and was elaborated by Mr. Scott. It was well worthy of attention; because, up to this time, railway managers had not felt confidence in single lines, from the fact of there being no reliable system of signalling at their command.

The remarks he had made in bringing forward this system would no doubt lead to considerable difference of opinion. The semaphore arrangement had cost him much time and trouble; and he naturally thought it better suited, than any other, to meet all the requirements of railway working. At the same time he must say, the telegraphist looked with some regard upon the needle,—having been brought to understand it, he knew what it meant—and personally he had such confidence in the needle, that he would just as soon use it as the semaphore. But a railway man looked upon the semaphore in the same way as the telegraphist did upon the needle;—he knew what it meant, and not understanding telegraphy, he naturally preferred those signalling instruments which corresponded to the out-door signals, with which he was thoroughly familiar. The London and North-Western Railway could hardly have a more perfect plan than that of Mr. Edwin Clark's, for their particular system of working two, three, and four trains in each division. But for tunnels and inclines he was inclined to think the semaphore was superior. It sometimes happened, that there was a tendency on the part of those whose schemes were not approved to consider themselves aggrieved. He hoped he had succeeded in getting through the subject without raising any great degree of feeling. He had endeavoured to avoid mentioning any circumstances, or expressing any opinions, without substantiating them by the narration of well-authenticated facts. Where this was not done, he hoped his long experience would be received as a guarantee for the honesty and truth of his statements. All were apt to make the best that was possible of their own inventions, and that had undoubtedly been his endeavour on the present occasion; but in such a place personal feeling and personal interest ought to be subordinate to that higher object—the advancement and the perfection of that railway system which was the mainstay of this country.

Mr. **Edward Tyer** said that he rose with extreme diffidence to open the discussion. He felt that justice had not been done to the system with which his name was associated, and he likewise thought other systems had been ignored, or had been passed over in a slight manner. His original intention was to have allowed the matter to pass unnoticed; but there were occasions when silence might be misconstrued, and he considered it a duty, both to the Members of the Institution and to himself, to lay before them, in as few words as possible, a full description of the instruments he had introduced, and to endeavour to answer the objections which had been raised.

He would record his thanks and meed of praise to Mr. Preece for the able and intelligent manner in which the Paper had been prepared. It was, however, an example of the great facility with which fault could be found when there was a disposition to do so; still the Paper was valuable, inasmuch as it filled a vacant niche in the archives of the Institution. Beyond that, he could not say much in its favour, as the majority of railway men and civil engineers had had this subject continually brought under their notice, and he believed every instrument had been more, or less submitted to their scrutiny.

Having been engaged for the last ten years in the practical development of his system, which he must be permitted to say, was one of the most efficient, it was natural he should pay great attention to the various topics introduced by the Author; and he confessed that he failed to discover anything new, either in the Paper itself, or in the particular instruments brought forward: indeed the greater portion of the Paper, as most of the Telegraph Engineers present were aware, had already appeared in print. Its object was now stated to be, to show to railway managers what had been done on other lines; but, from the manner in which the subject had been treated, the principal motive appeared to be to make known what had been done upon a portion of the South-Western Railway.

The system in operation on the South-Eastern Railway, which originated with Mr. C. V. Walker, whose labours in this field of inquiry were so well known, had only been cursorily alluded to. As Mr. Walker would doubtless supply this omission, Mr. Tyer would merely remark, that it comprised upwards of three hundred separate sets of bells, beautifully arranged, having various advantages, and being perfectly efficient for all lines where the traffic was not excessive. On the North Kent and the Mid Kent Railways, where the trains were very numerous, it was not found adequate for the requirements of the traffic: and there Mr. Tyer's instruments had been in constant use for the last seven, or eight years.

Mr. Preece had introduced, as a novelty, an instrument which, unfortunately for him, belonged to Mr. Walker, who, in 1854, brought out an instrument exactly coinciding with it, viz., a semaphore signal assimilating with the out-door signal, a persistent current causing the semaphore to be raised or lowered. Mr. Walker's Semaphore Electric Telegraph for train signals was originally described, thus:—"The shape, or configuration, of this electric telegraph is such as to correspond with the ordinary railway semaphores. It consists, as far as my design is concerned, of a model semaphore signal post, with a moveable arm or arms. The instruments are connected between two stations in pairs, and the arms are moved by electric currents acting in any of the usual ways. The handle is on the same side with the arm, and the arrangement is such that the arm and handle shall move in unison. When the handle is put up the arm rises, and the 'danger' signal is made; when the handle is put down the arm falls, and the 'all-right' signal is made. The object of giving this outward form to an Electric Telegraph for train-signalling is, that the signal shown on the train-signalling Electric Telegraph shall be the same to the eye, and have the same meaning as that shown on the common signal post; the meaning of which is so well known to all persons employed on railways, and which cannot be misunderstood." Mr. Tyer therefore claimed for Mr. Walker, the credit of having first assimilated the signals of electrical signalling instruments to the line signals of railways. Models of this instrument were shown at the International Exhibition at Paris, in 1855, where it attracted considerable attention.[1]

At the same time Mr. Tyer exhibited a pair of disc signals, coinciding in many points with the French system of using discs. Not only could signals be transmitted between station and station, by discs revolving through a quarter of a circle, but similar signals could be given to the driver of the train, while on his journey, so that he might be made aware, before arriving at the next station, what signals to expect. Experiments were carried out on this system, on a large scale, on the Paris and Strasburg line, and an Imperial Commission was appointed to inquire into the matter. But as it involved the expense of fitting up all the stations and engines with this particular apparatus, it was not then brought into general use. Other Companies, however, availed themselves of it, and at the present time there were about one hundred and fifty sets of these instruments at work on the Continent.

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[1] The labels then fixed on the instruments were—

"9. Sémaphore-électrique monté, pour signaler un convoi qui va partir."

"10. Semaphore-électrique monté, pour signaler un convoi qui va arriver."

The price of the pair was given as 6*l*.

Before attempting to reply to the various objections raised to his instruments, it would be expedient to explain the system itself and the manner in which it worked. The dial of each instrument was divided into two parts,—the upper portion referring to the up line, the lower portion to the down line. Each instrument had two indicators,—one red, the other black. The former always showed the last signal sent: the latter that last received, and this was unalterable by the man in charge. When either indicator pointed to the right hand, it showed 'line clear.' Bells and gongs were attached, relating respectively to up and down trains. One peculiar feature, which had not been introduced in other instruments until this arrangement was brought forward, was, that no signalman ever sounded his own bell, or gong; therefore, whenever he heard these sound, he knew it must be the station in advance replying to his own signal, and thus no mistake could possibly occur. In order to call another station, and to describe the particular train which was about to leave, it was only necessary to press in one of the piston rods attached to the front of the instrument, by which a current of electricity was transmitted to the station in advance, and the gong, or bell was rung, as the case might be. Two beats on the gong were employed for a down passenger train, three for a mineral train, and one as an acknowledgment that the signal had been duly received. Supposing a down train had left station A for station B, the signalman at A called B, by pressing in one of the piston rods twice. The signalman at B immediately knew that a train had left A; he then pressed in the left hand piston rod, which caused his red indicator to pass over to 'train on line,' and made the index at A coincide with it. A could not alter the needle on his instrument; and his instructions were to keep the ordinary semaphore raised, till, on the train arriving at B, the needle was released, by the signalman at B, which A acknowledged by one beat in reply. The same took place with up trains, in a reverse direction. But supposing that there was an obstruction at B, or shunting was going on, then the code consisted of five beats on the bell, or gong, with this important distinction, that instead of being acknowledged once, as in ordinary cases, it was replied to five times. The man at B caused the needle to go to 'down train on line,' and completed the signal by giving four blows on the bell. The man at A knowing the line was obstructed at B, replied to that signal by five beats on the gong. Thus there was a perfect record of every signal sent and received, and at any time of the day, or night, a signalman could, by the indicator, tell the station in advance, or in the rear, what signals he had last sent, or had last received.

Having described the nature and mode of operation, he would endeavour to dispel any illusions which might have been created, by the objections which had been raised.

First, with respect to the effects of atmospheric electricity, it had been stated, that his instruments could "be demagnetised and rendered useless."[1] Would any one conversant with this subject say, what electric telegraph was not liable at times to be demagnetised and rendered useless? Bringing these three conditions together,—a line wire, a pair of Mr. Preece's instruments attached, and then discharge the contents of a lightning cloud through them,—the result would be, that the whole arrangement would be destroyed; and instead of an uneducated pointsman being able to readjust the instrument, it was most likely that he would shut up his box, and get out of the way as quickly as possible. Mr. Tyer's instruments had been at times deranged by lightning, but he was not aware of a single instance, where atmospheric electricity had caused a false signal to be given. There were two indicators upon each dial. In other arrangements also there were two indicators, or two sets of bells; but in his system there was this peculiarity, that one-half of the needles being out of circuit, the chance of being demagnetised by atmospheric electricity was reduced by one half. It was impossible for the red needles ever to be affected by electricity, as they were out of circuit altogether. With respect to the black needles, when pointing to 'line clear,' if electricity of a positive nature entered it did no harm, as it would simply cause them to remain over to 'line clear;' while if pointing to 'train on line,' and a negative current of electricity entered, it would do no harm, as that was the current requisite to produce the 'train on line' signal. But the question arose, supposing the needle were to turn from 'train on line' to 'line clear,' what would happen? The needle could not be put over from one signal to another without ringing the bell, and before the needle went over, the coil would in all probability be destroyed. If it did go to 'line clear,' the signalman would know that no train was due, none having been previously signalled; he would then refer to the train-book, and if he had any doubt on the subject, he would raise the semaphore and stop the train. If there was no doubt, all the man had to do was to bring the needle to 'line clear,' and then to obtain an acknowledgment, when the signalling would go on as usual. The statement, as to the needles being demagnetised, was incorrect, as that could not possibly take place, for the needles were not permanent magnets, as in most other instruments, but were simple pieces of soft iron, which received their magnetism by induction, from being suspended in close proximity to the coil of wire, through which the charge flowed. The permanent magnet was used simply to retain the needle over, and was quite away from the coil, and was not influenced by currents traversing it. Some of his instruments had been injured by lightning, but the charge had been of such a nature and in such volume, that the instruments had been completely destroyed. Two such cases had occurred on the Great North of Scotland Railway, where it had been necessary to provide new instruments; but he never knew an instance of the needles going over from 'train on line' to 'all clear' which would have misled the signalman on duty.

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[1] *Vide ante*, page 185.

Another objection raised was, that his instruments only required one line wire, whereas in other systems two or three line wires were necessary. Now, in spite of this opinion, he believed one wire to be an element of safety, as well as of economy. If three line wires were employed, and a fracture took place in one of them,—which was not unfrequently the case,—the fractured wire might foul one, or other of the remaining wires. With persistent currents flowing through the fractured wire, or either of the others, false signals might pass into the instruments, and thus lead to confusion and possibly accident. Whereas, with his instruments, in the event of a wire breaking, when a signalman was not able to call the attention of the station in advance, the signal was repeated, and if there was no reply, he was made aware that something was wrong, and he immediately raised the semaphore; because the rule was that no signal was complete, unless it was acknowledged and entered in the book. Therefore, the moment anything happened to the instruments, the semaphore was raised, and information was forwarded to the next station that the telegraph was out of order. Again, with persistent currents there was the liability of the battery getting weaker and weaker, and not indicating the true signal clearly. Now, with his instruments a very low battery power was sufficient to move the needles from right to left. Should it however begin to get weak, still the needles would not be affected; but this state of the battery would be indicated by the fainter ringing of the bells at each station, and the person on duty would thereby be made aware of the fact, of the batteries requiring attention.

The next objection was, that his instruments were always kept under lock and key, and that no repairs could be effected, until the arrival of the superintendent in charge of the line. This was a weak argument; and he found in practice, that unless the instruments were under lock and key, they were liable to be tampered with, and he had no desire that the rough hands of the signalman should be employed in endeavouring to repair the delicate structure of the telegraph instruments. He had known instances of 'terminals' being undone and wires being broken off, and if, under such circumstances, a signalman should put the wires on to the wrong 'terminals' with persistent currents and needle arrangements, a different signal might be recorded to that which was registered at the opposite station. He strongly recommended, that all 'terminals' and connections should be under lock and key, to avoid any derangement from the signalman attempting to repair, alter, or tamper with, that which he knew nothing about. It was safer to wait for the superintendent, than to allow these things to be done by an ordinary signalman. He remembered on one occasion being sent for, a distance of 200 miles, on account of an instrument he had put up two days before getting, as was imagined, out of order. Upon his arrival, he found that a tin wafer-box had been placed on the top of the bell-case, and had completely closed the circuit, by making contact between the 'terminals.'

Another point raised was, that on lines where his instruments had been placed, accidents had occurred. He believed accidents had also frequently happened where semaphore signals were used. If the trains kept time, and the semaphores were attended to by the drivers, there was not any necessity for electric indicators. But in practice trains did not keep time; and hence electric signalling was a great auxiliary to the efficient working of a railway. Take, for instance, the two accidents which occurred on the South-Eastern line. The first was a slight accident on the Greenwich viaduct, where a train started on the wrong line of rails, and the mistake was only noticed when two trains came in collision. Why that error should be attributed to his instruments he was at a loss to conceive. With reference to another accident, he begged permission to read the following extract from Colonel Yolland's Report:—[1]

> "The signalman at the Surrey Canal Junction, who had been six years employed at this junction, admits that he did not give the 'line blocked' to the Commercial Dock Station when he lowered the branch line semaphore signal for the cattle train to come out on to the main down line, although it was his duty to do so, in accordance with the Company's regulations, and he therefore gave back a false signal to the Commercial Dock Station, in reply to the telegraphic signal, that the passenger train (8·5) was ready to start, in saying the junction was clear, when the trucks were rolling past his box, part being on the main down line, but the greater portion on the branch down line. And he says in extenuation, that he omitted to give 'line blocked' to the Commercial Dock Station when he lowered the semaphore signal for the cattle train to come out from the branch, because he considered that he could get the line clear before it would be required; again he says, he never did it before for a cattle train, but that he has done it for a light engine that has been standing there. He allows that it is against the Regulations. * * * *
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> "The Company's mode of working must undoubtedly protect the public

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[1] *Vide* "Reports of the Inspecting Officers, &c., 1862." Page 119.

from ordinary collisions, unless, as in this instance, the regulations for carrying on the traffic are broken, and combined with such infraction of the Regulations that the engine-driver failed to keep a proper look-out."

In that case the blame was put upon the right person, and the indicators being unalterable, he found he could not get out of it, and therefore confessed he had not done his duty. This was another illustration of the advantage of keeping everything under lock and key.

With regard to the needle instruments not having sufficient space between the signals, the Author said[1]:—

> "The two signals, denoting such different meanings—the one the element of safety, the other the source of danger,—are not sufficiently distinct in their opposite indications. On the line, the semaphore arm, at one time elevated, and at another depressed, is unmistakeable in either position. So with a disc, at one time visible, at the next moment obscured, no error can occur. But a thin index, in a dark, dismal hut, with only a slight movement from one side to the other, whether it be momentary, or permanent in its deflection, is not decided enough to avoid misconstruction when examined hastily."

At the present moment there were 50 miles of line fitted with instruments in all respects similar to the semaphore described in the Paper; inasmuch as the indicator moved from the vertical to the horizontal. But they had this important advantage, that while the needle pointed to the signal 'line clear' when in a vertical position, the moment it became horizontal, it not only indicated 'train on line,' but also showed the direction in which the train was advancing. In working his instruments, with one needle red and the other black, the former showed the last signal given, and pointed to the direction in which the train was approaching; but the moment a signal was given to the station in advance, the black needle fell to the horizontal, showing that the train had passed the home station, and was advancing towards the next. When the signalman received that intimation, he brought the red needle back to 'line clear.' Thus with two arms, the lower portions of which were behind a fixed screen, in the same manner as a semaphore, the signalman could not make a mistake. If the indicator was vertical, it meant 'line clear,' if horizontal, 'train on line;' showing in the latter case the direction, either up, or down, in which a train was passing.

In conclusion he must observe, that although the Institution might be the proper arena for discussing the relative merits of the constructive details of train-signalling instruments, railway engineers and railway managers would not decide so important a question merely from hearing what inventors, or patentees had to say about their own instruments. The proper evidence of efficiency was to be obtained from the persons in charge of the several instruments, and from the managers who had the supervision of them; and in his own case, Mr. Tyer felt convinced the unanimous verdict would be, that during the ten years the instruments he had described had been in operation, they had worked well, and that experience had proved his system of signalling to be one of the most efficient, simple, and economical yet brought under the notice of the railway world.

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[1] *Vide ante,* page 180.

Mr. C. V. **WALKER** said, as the extensive system of telegraph signalling in operation on the South-Eastern railway had been only slightly mentioned in the Paper, he deemed it incumbent upon him to make a few remarks, so that the Members of the Institution and the telegraph world generally might be made better acquainted with it. In doing this, he should, unavoidably, have occasion to refer to it in plain terms, as his own system. It was his own, inasmuch as he originated it, and it had been perfected under his care; he therefore felt a strong interest in it. It was not, however, the subject of a patent, so that he had no pecuniary interest in it.

From the remarks made by a previous speaker, it would have been gathered, that 'sound upon bells' was the basis of the system of train-signalling he was about to describe; without this, a leading feature would be gone. It would be right to place this matter historically correct before the Institution, in order that the origin of the bell-signal system, for which 'Honourable Mention' had been awarded at the International Exhibition, 1862, might remain on record. In the autumn of the year 1851, a want was communicated to him by the then Manager of the South-Eastern line. In his reply, of which the following was a copy, Mr. Walker described the system proposed to be introduced; and he had not since seen any reason to alter his opinion of its efficiency for train-signalling.

"SOUTH-EASTERN RAILWAY.

"*Electric Telegraph.*
Tunbridge, Oct. 29th, 1851.

"MY DEAR SIR,

"In respect to the signalman at the Spa Road indicating the character of the up trains to the switchman at the entrance of the South-Eastern and Brighton terminus at London, and to the latter having power to order either train to be stopped at the Spa Road,

"The distance is 820 yards. It would require two[1] wires, which could easily be erected.

"I should construct two bells of a totally different character to those used for the telegraph, and should use a different kind of battery.[2]

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[1] The second wire was not found to be necessary, the viaduct-earth being sufficiently good.

[2] This was the graphite battery (since platinized), for which a prize medal was awarded at the Great Exhibition, 1851.

One blow on the bell would indicate a Croydon train, two a Brighton, and three a South-Eastern. I would so construct the apparatus, that it could be relied upon. The expense would be very little, and it could not easily be deranged.

"Yours very truly,
"(Signed) CHARLES V. WALKER,
"*Engineer and Superintendent of Telegraphs.*"

"To CAPTAIN BARLOW,
"*Superintendent.*"

That letter described the foundation of the bell-system as now in operation throughout the South-Eastern Railway. The first pair of bells were fixed and used January 22-31, 1852. The specification of Mr. Tyer's first patent was dated July 20th of the same year. At the present time, the South-Eastern line was protected in every possible manner by bells of the kind described; there were three hundred and thirty bells in operation,—some being connected merely in pairs, some with intermediate bells, and in other ways. Of these, eighty-four were provided with counting indexes, which indicated the number of blows sounded, and the remainder were plain. The total length of the South-Eastern line, thus protected, was 275 miles; and 11 other miles of the line were furnished with Mr. Tyer's instruments. Signal-bells were in course of erection[1] on the Caterham branch of nearly 5 miles in length. The Angerstein branch of half a mile, which was without bells, was not used for passenger traffic. The Whitstable branch of 6 miles was provided with a pair of telegraph instruments, which were little used for speaking purposes, but served for signalling trains. From Ash to Shalford, upwards of 8 miles, belonging to the South-Western Railway Company, but over which South-Eastern trains ran, electric signalling was not employed.

With respect to the cost of the telegraph signal-bell system, and the amount that had been expended by the South-Eastern Company upon it, in order to promote the safety of the traffic, he might state that the total cost on the 275 miles had been nearly £3,650, or at the rate of £13. 5*s.* 3*d.* per mile, including wires, bells, and batteries complete. There was at the rate of one bell and a fifth for every mile, or one bell to every 1,466 yards; and the total cost on each 1,466 yards was £11. 0*s.* 11*d.* The average cost per bell, including the 'pecker' or ringing-key, taking the bells one with the other, plain and index, had been £4. 6*s.* 6*d.*; and the cost complete, including batteries, had been £5. 10*s.* 3*d.* The train signal-bells were in charge of the station-masters and the ordinary signalmen, so that the working expenses were not thereby increased to any appreciable extent. Loud-sounding bells, at least 4 or 5 inches wide across the mouth, were employed. The principle to which he had referred in his letter to Captain Barlow was, to wind the coils with No. 16 or No. 18 wire gauge, which was at that time an unusual size for an actual working telegraph instrument. The hammer which was attached to the keeper of the electro-magnet was the only moveable part of the bell apparatus. The signals were given by the number of blows struck; the code for all ordinary purposes, called in practice 'the General Code,' being one blow for an up train out, two blows for a down train out, and three blows for a train in. For blocking the line, the bell signal was five blows; clearing the line after a block, three blows, or the in signal given and taken twice. One fundamental and essential condition was, that every signal made by one man should be correctly repeated by the other man. If A made a signal to B, and the repetition was not given, it was an indication either of misunderstanding, or of something being wrong. No signal was allowed to be complete, until it was recognized by the return of the same number of blows that had been sent.

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[1] Since these remarks were made, the Caterham branch has been fitted with bells.—C. V. W. Feb. 2, 1863.

Independently of the above application, which was the simple and ordinary process of train-signalling from station to station, these bells were used in many ways and in a great variety of places; in fact, they were almost universally applicable. At the London platform, bells were the effective instruments for supplying a certain want. It now and then occurred that a South-Eastern tidal-train and a Brighton train were due to start from the respective London platforms at about the same time. Should the South-Eastern tidal-train be unable to start to the minute, the inspector on duty had access to a 'pecker,' which enabled him to strike a certain number of blows, three, on a bell in the box of the signalman who had the control of the entrance to both stations. This was an intimation that the South-Eastern train was not quite ready, and that the Brighton train might be allowed to go out.—Again, at every level crossing, without exception, on the South-Eastern line, bells were placed in circuit in the gate-house, to be heard, but not to be answered. In this way indication was given that a train was approaching, either from A or from B, according to the number of blows; and the gate-keeper, hearing the sound of the bell, was made aware when the gates must be closed, till the approaching train had passed. In cases where the gate-house was close to a station, the bell was so connected that every signal, sent to the station to which the gate belonged, from the station either to the right, or to the left, was heard at the gate-house.—Then again, on the London Viaduct, there were two up lines to protect, and three different kinds of up trains to be distinguished. Between London and Redhill, one blow was given on the bells for a South-Eastern train, and two blows for a

Brighton train. On the Bricklayers' Arms branch, a still greater distinction had to be made. There were four kinds of up trains and two kinds of down trains; and blows on the bells were arranged to meet these various circumstances. It was not desirable that bells should be required to express so many different things; but on that branch it was impossible to avoid it. The up distinctions were, South-Eastern Engines, Empties, and Goods, and Brighton Goods; the down, North Kent and main line.—Again, at Hastings, Canterbury, and Paddock Wood, moving trains were indicated to the porters, by a bell placed on the platform of the several stations. The men right and left of the stations did the signalling, a platform bell being placed on a continuation of the wire; so that, all that was taking place at the signal-box, and required to be known by the station-master, was communicated by the bell. If a train was signalled as coming from St. Leonards or Winchelsea, the station-master at the Hastings platform knew what train to expect. At Ashford, there were two junctions, which was another cause of complication, and several different signals had to be given by the bells. They were arranged in different groups, and spoke by the number of blows given. At Beckenham there was another extension of the same kind; and although the signalman was somewhat removed from the station, the station-master heard by a platform-bell the signalling that was going on in the signal-box, and had all the information he required of the various kinds of trains. At Margate the signals sent from Ramsgate were taken at the signalman's box, some distance from the platform, but these were heard also at the station. At Folkestone and Dover there were similar arrangements. Then there were small stations which were closed at night, when the communication with the bells ceased. In such cases the signalling was done by the stations right and left, which were switched into connection before closing. Repairs were now going on in the Bletchingly Tunnel, during which a bell was placed in circuit, in a hut at the tunnel mouth, within hearing of the men; and they were by its means made aware of the approach of a train.

One peculiarity about these instruments was, that they appeared to be the only kind of telegraph instrument that could be actually used, and that had been experimentally and successfully tried, with balanced currents. He communicated to the Royal Society, in 1857,[1] a short notice of the mode of working these bells with balanced currents. He subsequently found that a patent, of which he had not before heard, had been taken out by a Mr. Walker, of Glasgow; on looking to the specification, he could not, however, discover that any instrument had been conceived, by which the system could be worked; nor could he ascertain that any use had been made of the patent. When the bells were arranged with balanced currents, the guard of a train, which might have become disabled between two stations, had merely to fasten a wire to the bell line-wire, and each time he touched the rail with the other end of the wire, the bells at the stations on each side were rung. No batteries or apparatus of any kind had to be carried with the train.

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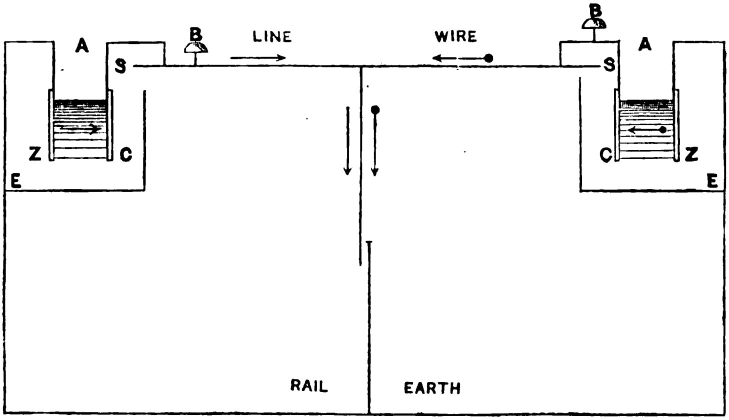
[1] *Vide* "Proceedings of the Royal Society," vol. viii., p. 418.

Fig. 13 showed the nature of the arrangements. A A were the two stations; B B, the respective bells; Z C, C Z, the station batteries; E E, the earth-wire; S S, the contact-springs of the peckers; the horizontal arrows, the direction in which the currents tended to move; but, as the currents were equal, and in opposite directions, the whole of the system was in a Rheo-electro-static state. For ordinary signalling, the pecker-spring at either station was merely depressed into contact with the point beneath; the battery at that station was thus thrown out of circuit, and the current of the distant battery flowed through the distant bell and rang it. If, on the other hand, the guard in charge of a train required to ring the station-bells on either side, he had only to twist one end of a wire on the line-wire, and with the other end to touch the rail, when the currents from both batteries would flow along that wire, as shown by the vertical arrows, and both bells would be rung; or contact-springs might be fitted to some of the telegraph poles.

Fig. 13.



Rheo-electro-static Telegraph.

The system of signalling was so efficiently carried out on the South-Eastern line, that such a use of the bells as he had just described was hardly to be looked for. If a train did not arrive within a few minutes of its time, it was tolerably well known that it had broken down. However, if necessary, nothing more was required for putting all the bells in use into this balanced condition, than to take a couple of wires off their terminals, and to interchange them. Another advantage of the large wires with which these bells were wound, was, that although the gutta-percha covered wires buried in the London Viaduct were perishing,—those on which the bells were at this moment working, giving what was technically known as 'dead earth,'—still the bells worked very well through these moribund wires. One of the bells, exhibited to the meeting, was plain; and the other had the counting-index, already mentioned, attached to it. That was his idea of a really useful index. The bell-system had been so thoroughly carried out, that in some of the signal boxes there were two, three, and, in rare cases, as many as four bells. The bells differed in tone, and in the position they occupied. Should the noise of an engine blowing off steam, or any other cause, make it uncertain to a signalman how many blows had been struck upon the bells, or which bell sounded, he would find them registered by the index, which pointed to the number on a dial. It was a simple mechanism—a pair of pallets and a scape-wheel on the arbor, which carried the hand of the index to the precise number of blows struck upon the bell.

With regard to the semaphore to which Mr. Tyer had alluded, and which was for making the very signals proposed by Mr. Preece, it was constructed by him merely as an illustration, about eight years ago, and was used at Tunbridge for some months. The pair of instruments now exhibited were alternate. They were shown at the Paris Exposition in 1855. The instrument was of very simple construction, consisting merely of a galvanometer needle, with a semaphore index as an outside needle; and did not differ in principle from Mr. Cooke's needle, originally used on the Norwich and Yarmouth line, and since employed on the London and North-Western Railway. Instead of an outer needle pointing right, or left to written words, it carried an ivory arm on the top of a semaphore pole to be set up, or let down, and required a persistent current to retain the arm in one of its positions, as Mr. Cooke's did for both positions; which should be avoided, when practicable.

Of all instruments which had an index Mr. Tyer's was the simplest and most certain. The manner in which that index was arranged was very ingenious. It was a soft iron needle, hung loosely at the end of the core of the electro-magnetic coil; this was an original and good idea, and such a needle would be less liable to derangement than many others. These needles had worked admirably on the 11 miles of the South-Eastern Railway before referred to. It must be borne in mind, that these indexes did nothing more than move to the right or to the left; more than this was required, and, as it had been seen, by the bell-system much more was done. The bell-system had been introduced by Mr. Bartholomew on the Brighton line; he had, however, made his bells much smaller, and had added an index with two positions. Mr. Rudall had also adopted the pure bell-system on the London, Chatham, and Dover Railway, employing smaller bells; but Mr. Walker thought it would be more convenient in all respects to adhere to the use of large bells.

The objection he had to an index was this:—His idea of train-signalling was, that a good understanding and communication should be established between two neighbouring stations. In explanation of his views, he had forwarded to the Institution of Civil Engineers, in the year 1856, a Paper on Train-Signalling; but the subject not being then attractive, it was not read. On looking through this a few days ago, he found that there was scarcely a word in it which he would now strike out; and the Paper could as profitably be read now as then. He would merely refer to it in illustration of the principles of train-signalling adopted on the South-Eastern line, and the instruments with which he had brought those principles into practice. The bells now in use were identical in their minute details with those therein described. He read from the Paper four conditions, which appeared to him then, as they did at the present time, to be the basis of all train-signalling. There should, in the first place, be a good speaking understanding between the men at two neighbouring stations, A and B; and the four telegrams which were necessary between them were these—1st. 'May I send a train?' given by station A striking one blow to B; 2nd, 'Yes, you may,' one blow struck back by B. Nothing could be simpler. The blow was a loud one, distinct in its sound, and readily understood. The third communication would be from B, 3rd. 'The train you sent is in safe,' intimated to A by three blows;—to which the fourth message sent back from A; 4th, 'All right, I understand train is in,' A repeating B's three blows. These four signals were booked by each station; the time at which each signal was completed being entered in the proper column, so that a double permanent record was secured. The admirable manner in which these messages were booked was shown in a late Government inquiry. Without unduly boasting, he might state, that no collision had ever occurred on the portions of the South-Eastern line where these bells were in use, which was no bad illustration of how successfully they worked.

One chief reason why he continued to object to semaphores and indexes was, that the second of the above-named four signals was always contradictory, and did not mean what was intended to be conveyed. The first question was, 'May I send a train?' The answer with the combined bell-and-index system would be, 'Yes, you may not:' that was, whilst the bell reply said 'Yes,' the semaphore went up, or the index went over, which meant 'no.' It was true the 'no' was understood to refer to any train that might follow the one in question, although it did not say so; but some day the index might say 'no,' and mean 'no.' In his mind the signal was complete as soon as the men had exchanged signals and had booked them.

Mr. Tyer had stated that his system was used on the North Kent line, because the traffic was so heavy, and Mr. Walker's bell-system was not considered adequate. This was an error. The traffic was greater on the three lines on the west side of the viaduct run over by the South-Eastern, the Brighton, the Croydon and the Crystal Palace trains, where the bells alone were used. For instance, the average number of trains on week-days was one hundred and ninety-six, and in one year seventy-eight thousand six hundred and seventy-six; and on the day of the Foresters' Fête at the Crystal Palace, August 19, 1862, five hundred and thirty-five trains were booked, as having been 'bonâ fide' signalled by one pair of bells; and without that system it would be impossible to work the present traffic on portions of the South-Eastern and the Brighton lines, including the Croydon and the Crystal Palace branches. He had introduced this system in the ordinary performance of his duty to the South-Eastern Company, and he thought there were many other lines where it would be found as useful, and at a very moderate cost.

Before concluding, it was only due to the late Professor Barlow to say, that he was nearly becoming the discoverer of the electric telegraph; but his progress was arrested when he found that a galvanometer wound with a large wire would not work effectively at long distances.

Mr. C. W. **Eborall** could fully corroborate Mr. Walker's statement, with regard to the efficiency of the system of telegraph signalling in use upon the South-Eastern Railway. He believed that Company went further than any other in the kingdom, in carrying out what was technically called the 'block' system of telegraph train-signalling; for with the exception of a portion of the South-Western line, between Shalford and Ash, and of 12 miles of the Brighton line, between Redhill and London, that system was completely carried out on all the lines over which the South-Eastern trains ran. He had for many years endeavoured to induce the South-Western Company to adopt the same system, but up to the present time he had failed to do so. Mr. A. Scott (the Traffic Manager of that line) had expressed the opinion, that it was a dangerous system; and Mr. Hawkins, of the Brighton line, likewise attributed danger to it. But Mr. Eborall was quite satisfied, it was a system which should be legally obligatory upon every Railway Company. He went to the South-Eastern Company prejudiced against the 'block' system; but after a short time he became satisfied that it was the right one to work trains upon a railway, with any degree of safety—especially on lines with trains running at high speeds, and at irregular times, to suit the emergency of the traffic. The tidal trains on the South-Eastern ran at very high speeds, as well as those carrying the Continental mails. He could not agree with the statement as to the great punctuality of the trains on the South-Eastern line, because irregularities sometimes occurred from working in connection with steam-boats; and at the present season of the year, the boats were uncertain in the times of their arrival at Dover and at Folkestone. He would impress upon every one connected with railways, the necessity of looking closely into this matter. It was worthy of attention; because if a proper system, such as he believed that practised on the South-Eastern to be, were adopted, fewer collisions would take place upon railways. With reference to Mr. Tyer's system, it was no doubt a very good one, but he did not think it was better than Mr. Walker's. Both had been adopted on different portions of the South-Eastern line; but Mr. Tyer's was only applied exclusively on 11 miles of that railway, and on that part nothing could be better than the manner in which the trains were signalled by it.

Mr. ARCHIBALD SCOTT said, with reference to the statement that Mr. Eborall, had vainly endeavoured to induce the South-Western Company to adopt the 'block' system of signalling, in working a portion of that line, he was not aware of the suggestion having ever been brought before that Company in such a way that it could be decided upon; and they had certainly not declined to adopt the system on the portion of line alluded to. If it was asked whether he approved of the 'block' system, his answer would be, that he did not as a general rule. Indeed he believed that, upon a main line of railway, its use would be disadvantageous. His experience of the 'block' system was principally gained on a portion of the South-Eastern line, from Wokingham to Reading. The distance between those place was 7 miles, and no train was allowed to leave Wokingham until the preceding train had arrived at Reading. Fifteen minutes were required on an average for that distance, so that a train, under that system, might be detained fifteen minutes at Wokingham, before it was allowed to go on to Reading. He did not consider that upon any ground of public safety such a detention was called for. There might be portions of a railway so crowded with traffic, that the telegraph would become an essential element of safety; and in such cases the 'block' system might answer very well. But so long as the traffic could be carried on without the necessity for its aid, there was, in his opinion, a positive advantage in ignoring it, and in depending upon the ordinary mode of signalling.

With regard to the different methods adopted by Telegraph Engineers, he could only accord the highest praise to all. He believed the utmost ingenuity had been devoted to the application of the electric telegraph for railway purposes. Mr. Tyer had bestowed great pains upon the development of his system, which was an admirable one. Mr. Walker had adopted another plan, and had exercised his ingenuity with very good results. The same might be said of Mr. Preece, and of the instrument he had brought before the Institution. Mr. Scott hoped these efforts would not be relaxed, and that constant endeavours would continue to be made for perfecting the system of railway telegraphs. At the same time he would caution railway managers, as far as possible, against being wedded to the telegraph, under the impression of thus securing safety. His opinion was that it was a mistake, unless the telegraph was kept within limits. As an auxiliary it was no doubt an admirable agent; but if too much reliance was placed upon it, he believed its tendency would be rather to introduce an element of danger.

Mr. EBORALL explained, that the detention between Wokingham and Reading, which had been alluded to, did not affect the principle—it had been occasioned by the want of an intermediate signal, which was now being fixed; so that the interval of time would not be in future more than seven and a half minutes instead of fifteen minutes.

Mr. GEORGE HAWKINS observed, that the Brighton Company were not opposed to train-signalling by telegraph. He had endeavoured to carry it out on that line, but as an auxiliary only, for in his opinion anything which had a tendency to lessen the caution incumbent upon an engine-driver would increase the danger, rather than diminish it. That was the reason why he had not adopted the electric telegraph so fully as he might otherwise have done. Although on the crowded portions of that line other precautions than the ordinary signals were required and adopted, yet he considered that the 'block' system of working would be impracticable, except with such a larger number of signals and signalmen, as to increase the liability to mistake, and so render the alleged additional safety very questionable. He was able to speak from experience in terms of unqualified praise of Mr. Tyer's system, and he was not aware of a single instance of failure, or where the persons working it had mistaken the signals recorded. He was fully satisfied of the utility of telegraph train-signalling as an auxiliary, under proper restrictions, but he should be sorry to depend upon it alone, as it might lead to a want of attention to the signals on the part of the engine-drivers.

Captain HUISH, as one of the oldest railway managers in this country, and the first, he believed, who introduced, to any considerable extent, the system of telegraph train-signalling, and also as having, since his retirement from the London and North-Western Railway, taken a somewhat active part in the promotion and extension of the Electric Telegraph, felt deeply interested in this question. The subject, although frequently referred to in the annals of the Institution, had not yet undergone that thorough discussion on the part of railway managers which it deserved. He would not occupy time by noticing in detail the various plans which had been produced; because in his opinion a far wider view should be taken than was involved in the isolated question whether a needle, or a disc, or a repeating signal, or a little semaphore, or a bell was the best mode of effecting the object. In passing, however, he might say he very much distrusted the bell-system. The ear and the eye too were both organs which were apt to be misled—the ear especially. The continual and monotonous repetition of the same thing deadened the effect, and he doubted whether, after hearing five hundred and thirty-five bells ring in one day, it would be easy to distinguish very clearly when the five hundred and thirty-sixth signal was given. The constant repetition of any sound had the effect of confusing the mind; and he believed there was nothing more liable to deceive than attending perpetually to the sound of bells. Even the eye too was liable to error, and the constant motion of the needles had a tendency to produce weariness. Therefore, although he had worked for many years, to a great extent by the aid of the telegraph, he thoroughly concurred with the remarks made in the Paper and in the course of the discussion, that the Electric Telegraph was a dangerous instrument to trust, as the primary agent in the working of a railway. As an auxiliary, telegraph train-signalling was invaluable, and circumstances were continually arising, which temporarily called it into play as the primary and indeed sole agent, and rendered its application indispensable. He remembered on one occasion, while on the London and North-Western Railway, that there were fifty hours' consecutive dense fog; and during the whole of that time the enormous traffic of that railway was carried on exclusively through the agency of the telegraph. One reason of his hesitating to place implicit reliance upon the Electric Telegraph was, because telegraphists themselves were liable to error. In the Electric and International Telegraph Company, with which he was connected, it was found that the best clerk in the establishment made a mistake once in five thousand nine hundred and eighty times. When the length of public messages was compared with the simple work of signalling trains 'in' and 'out,' the mistakes would doubtless be much fewer in proportion in the working of a railway. Still blunders would unavoidably occur; and as on many lines there were six hundred, or eight hundred trains in a day, they must soon, on the system of averages, arrive at a point when one of those mistakes might involve the most serious results. Highly, therefore, as he appreciated the marvellous facilities and the great power which the possession of the telegraph conferred on railway managers, he agreed in the opinion that the telegraph should not assume a more important position on railways than it deserved. At the same time he was convinced that Railway Companies had not given that attention to the subject which it undoubtedly deserved; for the telegraph enabled managers to expedite, under extraordinary circumstances, the passage of trains, and to economise time and money, and as auxiliary to and corrective of other signals it was productive of increased safety.

With regard to the London and North-Western line, he knew of no system superior to the very simple one which he left there some years since. The distance of 83 miles between London and Rugby, was divided into lengths of 2½ miles, and at each point there was an instrument with two signals for the 'up' and 'down' lines. The simpler the system could be made, the nearer would comparative safety be attained; and although three blows on the bell for one signal and five blows for another might seem pretty in theory, he was satisfied that it would be better to return to the simple indications of the needle; and it was most desirable to endeavour to enforce uniformity of operation.

Another question arising out of this Paper, was the danger of working single lines by the telegraph alone. He held that a single line, under proper regulations, might be rendered even safer than a double line. Parliament had recently granted running powers to various companies over the lines of other companies: and in the last session that principle was extended, by giving running powers to competing companies over the same single line of railway. He believed this was a wise step, and that the single line might be rendered safer for competing companies to work over than a double line. But then the telegraph must be ignored altogether, as the sole, or even the primary agent of safety. The only way by which a single line could be worked with absolute safety, was by the 'train-staff.' He should like to see it more extensively used, and as he travelled a good deal on a single line belonging to the South-Western Company, he should feel more comfortable if the working was conducted on that plan. The train-staff could scarcely go wrong, whereas in the manipulation of the telegraph one mistake might be fatal. With the train-staff there must be the consentaneous mistake of three men to produce a collision; the station-master who had charge of the staff, the guard who received it from the station-master, and the engineman who could not move till the staff was produced. Under that system a dozen companies, although doubtless subject to delay, might work over the same line with absolute immunity from danger, which was after all the main object of every manager. The telegraph alone in such cases was a source of positive danger. Allusion was made in the Paper to an accident on the Hereford line from the omission of the word 'at,' and he knew a very recent instance, in which a family was brought from Switzerland, and an establishment in England broken up, through the omission of the word 'not' in a telegram. He therefore for one must decline to rely exclusively on the telegraph under any circumstances, and as the primary agent he would caution railway managers against its unrestricted adoption.

Mr. **Fleeming Jenkin** believed that the point of real importance in this discussion was, what system of signalling should be adopted; and whether if the 'block' system were thought the best, it could be strictly carried out. He regretted that experience did not entitle him to speak on this point; but he would briefly refer to the several instruments by means of which the block system could be conducted.

The Author of the Paper alleged, that Mr. Tyer's instrument could be deranged by atmospheric electricity. On that point Mr. Jenkin agreed with Mr. Tyer's reply in almost every particular; as the instrument was not peculiarly liable to be deranged by atmospheric electricity. The little needle which was deflected was not a permanent magnet, and could not be demagnetised; and therefore, although one wrong signal might be sent by a current of atmospheric electricity, no series of false signals could be transmitted, as might happen if the magnetism of a needle were reversed. The only permanent magnet in connection with the instrument was placed outside the coils, and could not be influenced by those coils. A momentary atmospheric current would, however, produce a permanent alteration in the signal; a fault which did not occur in some other systems. The instrument was also very simple, and only required one wire from station to station; whereas every other system involved the use of at least two wires. Another merit was, that the batteries employed were not permanently closed. The current was not kept constantly flowing through the wires, and consequently the batteries did not deteriorate so rapidly as in those systems in which a permanent current was maintained. One defect of this instrument was, that it did not show immediately any failure that might have occurred in the circuit. If the batteries were out of order, the needle remained where it was placed, and could not be altered; whereas by the system of

Mr. Edwin Clark, on the London and North-Western Railway, in the event of any interruption in the working, the needle became vertical, and the signalman at once knew that something was wrong with the circuit. But Mr. Tyer's instrument had what might be considered a more serious fault, although it was evident that it was not generally so regarded, as several railway managers had declared themselves perfectly satisfied with the instrument. If, for instance, it was wished to move the black needle at the distant station to 'train on line' one button, or piston-rod had to be touched; while, when it was desired to move it back to 'line clear' the other button had to be pressed. In each case the red needle at the home station followed the motion of the distant black needle, and so far nothing could be simpler. But signals had to be sent, when neither needle was required to move, when the gong, or bell only was to be sounded, to call the distant station, that it might send back the permanent signal. Now, to send this call, sometimes one and sometimes the other button had to be pressed, according to the position of the little red pointer. To send one and the same signal two different buttons had to be used at different times, and if the wrong button were chosen, the needles showing the condition of the line would be altered when they ought not to be moved.

Mr. Jenkin then referred to the electrical peculiarities of Mr. Edwin Clark's instrument, about which little had been said in the course of the discussion, except by Captain Huish who had stated, that in practice it had fulfilled its purpose extremely well. It was a needle instrument, and only those who were acquainted with telegraphy could appreciate the advantages which were expressed in those words. These instruments were made of a common magnetised steel needle, balanced on two pivots. There was the least possible amount of friction to restrain the motion of the needle; the action was of the simplest kind, and was scarcely liable to be deranged. The block system was worked by this instrument in the same manner as by Mr. Tyer's. The man at one station called another station by a temporary signal, and the man at the other station made the signal permanent. In that respect the system was the same in both. But if anything went wrong with the electrical circuit, it was at once shown by Mr. Clark's instrument; and it had not the serious defect, that at one time the signal sent by a given handle meant one thing, and at another time it meant another thing. The temporary signal, or call, was given by a temporary movement of the handle, the permanent signal by a permanent alteration in the position of the same handle. The only objection urged against it was, that the needles were liable to have their magnetism reversed. If that happened, the signals sent would be false; but he did not think that would necessarily lead to accident, or mistake, as a complete signal consisted of a signal sent and an answer received, and unless the two corresponded, which would not be the case if the needle of one instrument had its magnetism reversed, there would not be much risk of error. Moreover, he did not think this was an accident that frequently happened, and if proper precautions were taken, it could never occur. It was quite possible to provide every station with an efficient lightning protector of the most simple description, consisting of one iron plate lying on the top of another, and that would act as an almost perfect protection against the effects of lightning. Further he would say, that rather than use inferior, or more complicated, instruments, he would prefer to put up an extra wire, in connection with the earth, from post to post, along the whole line, and then there would be perfect security against the action of lightning. A momentary atmospheric current of insufficient strength to demagnetise the needle would on this system do no harm; inasmuch as the permanent battery would bring the needle back to its proper place. In Mr. Tyer's instrument, on the contrary, the momentary atmospheric current would produce a permanent effect.

With regard to Mr. Preece's instrument, he would in the first place refer to it as used to give a negative and a positive signal, or, in other words, as an instrument which could be employed as the two others were in working the block system simply. As an instrument, he thought it inferior to the simple needle instrument. There were several hinges, and at each there was a liability to stick. In addition there was a cog-wheel and rack, and the great motion of the semaphore arm, as compared with the small motion of the armature, placed the latter at such a disadvantageous leverage, that the slightest check to the end of the semaphore arm would prevent the motion of the armature, whether moved by the current, or by the weight, unless very powerful currents were had recourse to; and the utmost force caused by the electric current was very feeble. Moreover, the working parts were much exposed to dust and dirt. As regarded the action of atmospheric electricity, only soft iron being used, there was no needle to be demagnetised; but that advantage was counterbalanced by a peculiar property of soft iron. With a soft iron electro-magnet, when an instrument was adjusted to work with a delicate current, if a strong current passed, such as would result from atmospheric electrical action, a certain amount of magnetism would remain in the soft iron, and that would retain the armature down when it ought to let it rise up. On the other hand, if the instrument was set to work with strong currents, the time might come when considerable leakage would take place, and when the current would be too weak to move the armature at all. In needle instruments there was a gradual scale of effects, and the weakest currents of electricity were sufficient to show something. He therefore preferred the needle instrument. He considered that when a needle was permanently deflected on one side, a signalman was as likely to understand that, as the little arm of the semaphore; but if semaphores were used at all, he preferred that on Mr. Walker's plan, which was a red arm placed on a needle. There was but one pivot, and some of the disadvantages he had referred to, in connection with Mr. Preece's system, disappeared. In Mr. Preece's instrument if anything went wrong with the circuit, the instrument would not show it, and so far it was inferior to Mr. Clark's; but the semaphore arm would point to danger, and in this respect be better than Mr. Tyer's. Mr. Preece had suggested that not only should the call be answered by a permanent signal, but that this answer should be acknowledged by a third signal, and moreover that the receipt of the answer should be acknowledged automatically by the instrument. That arrangement necessitated the use of five wires for a double line, whereas Mr. Clark's only required two, and for Mr. Tyer's only one was necessary. The question of expense might be no great consideration, but a system of automatic contacts ought to be avoided. The force of electricity at disposal was small; the contacts were always points of danger, as the smallest particles of dust were sufficient to cause them to fail. The third automatic signal appeared to him to be a defect rather than an advantage.

With reference to Mr. Walker's instruments, and others which did not leave a permanent visible signal, he thought they threw too great a strain upon the attention of the signalman. In his opinion, Mr. Clark's system, as in operation on the London and North-Western Railway, had fewer practical objections, and was therefore safer, than any other. The using-up of the batteries was of little consequence, and with the exception of requiring protection against lightning, he did not think it stood in need of any improvement. Probably no one rigid system of signals, such as was strictly required for the block system, would meet all the requirements of the railway; and possibly there ought in all cases to be an extra wire between stations, with a bell, or speaking instrument, supplementary to what might be called the block instrument.

Mr. BARTHOLOMEW could not allow the remarks just made to pass unnoticed. Great stress had been laid upon the advantages of the London and North-Western system; now, although it might be a good one, it had this serious defect, in common with all needle instruments, that it could be used for other purposes than train-signalling. He thought no system of mechanism intended for train-signalling should be able to be made available for anything else. One objection urged against Mr. Preece's instrument was, that as there were so many pivots, the chances of derangement were increased. That might be correct; but it must be borne in mind, that the action of the electricity, which had to work upon the short end of the lever, was to show the 'all-clear' signal. If, therefore, anything went wrong, from the battery becoming weak, the semaphore arm was immediately raised to 'danger;' and though this might involve the temporary stoppage of a train, a short detention, under the protection of a back station, was preferable to having a false signal to proceed, whilst there was an obstruction upon the line.

The discussion appeared to embrace two separate questions,—first, as to the peculiar kind of system to be adopted, and secondly, as to the advisability of signalling trains by telegraph. He gathered from some of the observations made by railway managers, who ought to be most competent to judge what was necessary for the protection of the traffic, that the telegraph had better be dispensed with altogether, so far as regarded the signalling of trains. He thought those managers who raised objections against the block system, on the ground of it causing unnecessary detention, lost sight of two points. Usually signal stations coincided with passenger stations; but on the South-Eastern Railway, when the latter were so far apart as to retard the traffic, with such an interval of space between the trains, the distance was subdivided. If the distances between the signal-stations were made to correspond with the maximum amount of traffic likely to arise on any particular section of the line, then this objection to the block system, that it unnecessarily delayed the traffic, would be at once removed. Another point was, that whilst the block system was ignored as an advantage on the open line, its importance was admitted in tunnels, where the greatest caution was required. It was said, that anything which might distract the attention of the engine-driver from his straightforward look-out, must be objectionable; but in a tunnel full of steam, the look-out of the engine-driver was of small value to the safety of a train, which was then solely under the protection of the block system.

He was rather surprised to find that his system, which had been in operation for eight years on the most crowded part of the Brighton line, including the whole of the Crystal Palace traffic, and during five years without his surveillance, should have been overlooked; while Mr. Tyer's instruments, which had only been in use for a few months, on a small portion of the less crowded part of the line, were stated to have answered extremely well on that railway. Both instruments, perhaps, had their own peculiar faults, in common with all others. One great defect in all the systems that had been spoken of, was that arising from the failing of the batteries.

Professor Wheatstone's arrangement of magnetic signals, which he exhibited, coincided with his idea of what train-signalling ought to be. As there was no voltaic battery, there was no diminution of power; and it would be as available twenty years hence, with ordinary care in guarding against rust, &c., as at the present moment. Their power was also far beyond the limit to which any train-signalling instrument was required to work; the instruments now shown being capable of working over 100 miles of railway, whereas they were then speaking of sections of only 5 or 6 miles in length. There was, therefore, a great surplus of power. These instruments had also this advantage, not possessed by any other with which he was acquainted, that whilst they might be arranged so as to give two signals only, either 'train on line,' or 'line clear,' a large number of other signals could likewise be inserted. For instance, on the Edinburgh and Glasgow Railway, between the Cowlairs and the Glasgow stations, there were instruments of this construction, arranged for transmitting fifteen signals, which had given great satisfaction.

It was well known that three signals were given by all station signals—'all clear,' 'danger,' and 'caution.' Now, he should like any one to point out the value of the 'caution' signal as at present employed. He had frequently remarked to those connected with traffic on railways, that it was a dangerous signal in itself. He knew places on lines of railway at which the signals were always either at 'danger,' or at 'caution.' The 'caution' virtually meant in such cases 'all clear,' and the engine-driver, becoming aware of the nature of the supposed impediment which existed on that portion of the line, from the frequency with which he passed the spot, would, in ninety-nine cases out of a hundred, never take the least notice of the 'caution' signal. On the Great Western line, the 'caution' signal was given by a policeman with his hand, and he thought it a good system, as the signal was only given on peculiar occasions, and when really required. But the semaphore with the arm always at 'caution' meant nothing.

Another point, which was deserving of greater attention than it had received, was the advantage of having indexes at level crossings, in connection with the train-signalling apparatus at the adjoining station. This appeared to be adopted in Mr. Walker's system on the South-Eastern line. When the stations were 3 or 4 miles apart, or where the curves would not admit of the crossing-keeper seeing what was coming till the train was close upon him, it was of the utmost consequence, that the man should be aware when anything had left the stations on either side.

When railway managers stated that they did not like the telegraph,—that it was subject to derangement, and might be a source of error,—he did not think it got credit for the accidents that were avoided through its agency. When an accident took place, the cause was attempted to be discovered, so that the blame might be fixed upon some one, and possibly a child employed to work the signalling apparatus, became the scape-goat. As long, however, as the traffic went on smoothly, no credit was accorded to the telegraph. His own opinion was, that if any derangement occurred in the working of the train-signalling apparatus, it was owing to managers not giving the telegraph its due importance. In fact boys, occasionally mere children, were employed to work this apparatus, sometimes by day and sometimes by night, for twelve hours consecutively, because the pay allowed would not procure the services of men, who could appreciate the importance of the right use of the apparatus under their control. It was like expecting good workmanship from an unskilful workman, simply because he had good tools to work with.

Mr. CULLEY said, he had no system of his own to bring forward, nor even a pet scheme to defend; but for the last seventeen years he had been intrusted, at different times, with the management and maintenance of the Electric Company's telegraphs and of systems of train-signalling, in Scotland, and on almost all the lines of railway in the West, the Midland Counties, and the North-west of England. He had consequently visited a large number of tunnels, and had been able to learn from the signalmen in charge what they had most confidence in. He had found the system of permanent signals preferred to those in which the same wires were used for both lines of rails, and by which trains were simply 'reported' as in or out of a tunnel. It was true that the want of a permanent visible signal was in some measure compensated for, by the entry of each signal in books provided for that purpose; but unless the entry was made at the moment, there was danger that it might be neglected, and the book be made up afterwards. At Springwood, near Huddersfield, there were two tunnels, connected by a short open cutting, in which cutting was a junction with another line—a most difficult point to work. There were three cabins with telegraphs. So much were the men impressed with the necessity of having a permanent signal, that they invented one of their own, consisting of a piece of red rag placed on the instrument when there was a train in the tunnel, and removed when it was reported clear. This red rag was he believed now replaced by a card. Generally speaking he found temporary signals were adopted for the sake of economy: but it was not so in the instance to which he referred, for double-needle instruments were used, and one wire might have been appropriated to the up line and the other to the down line without extra expense. He had heard that the block system was about to be adopted at this place.

Bells to indicate 'line clear,' or 'line blocked,' seemed more objectionable than the system of temporary needle signals; because the eye was more to be depended upon than the ear. He had never had to maintain a bell-system; yet from what he knew of bells, he should be sorry to trust the safety of the line to the accuracy of observation of the number of strokes. He merely ventured this general opinion, as he might be prejudiced in favour of the needle. He had not any experience of the working of Mr. Walker's system, but from what he had heard of it, and from what he knew of the apparatus used, he believed it was the best bell-system that had been introduced.

Mr. Preece had omitted to mention, in his description of the block system, as used at the Clay Cross tunnel and elsewhere, that when the signal 'line clear' was given, on the exit of the train from the length protected by the telegraph, it should be repeated, or acknowledged by the man at the end at which the train had entered. This repetition was the safeguard against error, and against failure from demagnetisation, reversal and accident to the wire, or the apparatus. He was aware that it was not always insisted on, for a few months since he heard of a narrow escape. At the place he referred to, the 'block' was taken off, by simply releasing the needle and allowing it to remain upright. The instrument at the cabin towards which the train was running happened to fail, the needle dropped, but the man very promptly managed to restore the current, although not until the semaphore at the end by which the train entered had been lowered. But if the correct practice had obtained at this tunnel, the sudden failure of the block would not have led to the lowering of the semaphore. It would have been seen that there had been no reversal to 'line clear,' and on trying the instrument, it would have been at once perceived that something was wrong. If the needle were even first reversed by lightning, so as to give a false 'line clear,' and then at once demagnetised, it would be discovered in the act of acknowledging, or of repeating the signal. If demagnetised the needle would not answer the handle at all; if reversed it would move in the contrary direction to the handle. Mr. Edwin Clark's system required permanent currrents, and enabled three, instead of two distinct signals to be given. It also allowed of the danger signal being sent from any part of the section. He had no recent experience of Mr. Tyer's system. He had charge of it some years since on the Great North of Scotland and on the Furness Railways. Each system had its own peculiar faults and advantages. It was, in his opinion, most important that the faults should be similar to those of the other telegraphs on the line, so that the man in charge should not have a new set of symptoms to learn. It was an objection to Mr. Tyer's system that its faults were peculiar to itself, and required a special training; this objection might not be very serious, but it had its weight. Mr. Preece's system could be easily maintained by any ordinary lineman accustomed to alarums. Tunnels were generally difficult of access by the telegraphic superintendents, and few trains could be found which stopped even within 2 or 3 miles. But if a simple apparatus were used, the signalmen themselves could attend to it. They could be trusted to clean the batteries, to magnetise the needles, and to replace a broken wire. It was rarely the case that this class of men could not be trusted so far, whereas a less simple apparatus, however beautiful, or ingenious, could not be left in their hands.

If it were really desirable to assimilate the telegraphic to the ordinary signals, Mr. Preece had most effectually and ingeniously met that requirement. Mr. Culley could not agree with those who condemned the electro-magnet, because it gave no notice, but failed suddenly. It could not be denied, that the needle was superior in this respect, but an intelligent man would not fail to discover symptoms of lessening power, in the gradually decreasing force with which the arm was lowered. The electro-magnet could not of course be demagnetised, or reversed, and even if the current failed to attract the armature, no accident would result from the failure of the current, for Mr. Preece had very properly arranged, that the current should drop the arm instead of raising it. He considered the needle system had an advantage over the electro-magnetic system, and those of Mr. Tyer and of Mr. Bartholomew. He thought the danger from the demagnetising of the needles, had been overrated, and that it might be considerably reduced by using longer needles. When the Electric Telegraph Company first started, needles 6 inches long were used, which only required to be magnetised about once in six months. The needles now employed were only 1 inch long, and they required magnetising very frequently. The advantage of the shorter needles was the greater speed with which they could be worked, and persons accustomed to work the instruments were slow to adopt the longer needle, even where quickness of signalling was not important. He had obtained permission to place longer needles on the Edinburgh and Glasgow Railway, because those instruments being used for trains, and the men not being able to magnetise the needles themselves, it was desirable that the needles should not be liable soon to get out of order; but he had considerable trouble in keeping them on the line, because those of the men who had been telegraph clerks found they could not converse with their accustomed rapidity.

The system of signals at the tunnel on the up side of the New Street Station, Birmingham, had been referred to, as requiring an unnecessarily large number of wires. The Author of that system would perhaps permit him to give a brief explanation of it. The tunnel was at the foot of a steep incline, leading from the junction of the London, with the Manchester, Derby and Bristol lines. There were points and crossings at the station end of the tunnel, and even in the tunnel itself; and the trains from the different lines had to be shunted to their respective platforms. It was necessary then, that the pointsman should know accurately what train was coming. It was thought undesirable to indicate the trains by beats either of the needle, or of the bell, because a signal if misunderstood might cause a train to be sent on to the wrong line; and it was considered necessary to have a particularly distinct signal. There was first a double-needle instrument, to indicate the description of the train. The movement of the left-hand dial to the right indicated the main line London train, and to the left, the Midland train. The other signals related to the South-Staffordshire line, and to goods trains. When a train reached the ticket platform near the top of the incline, the first step was for the man at the ticket platform to block his indicating needle over to the name of the train coming down; thus asking the man at the other end whether the station was clear, or not, for that particular train. The reply was given on a third dial (showing only the two signals 'line clear' and 'line blocked'), by the pointsman at the switch box blocking his handle over. The signal indicating the description of the coming train was kept on, until it had passed the station points, when the pointsman took off the block, and the man at the ticket platform released the indicating needle. He was informed that, even with these precautions, it had been found necessary to introduce a supplementary pair of wires and dials for the ordinary block system, making five wires in all. Extreme safety was thus gained, and though there were many wires, each had its special use, and had been found in practice to be necessary.

Mr. HEMANS regretted that so many serious difficulties appeared still to exist in the perfection of the telegraph system; because he happened to be connected with several companies in Ireland, where single lines were in use to a great extent. He was rather surprised to hear, from so eminent an authority as Captain Huish, that the 'train-staff' system, as it was generally called, for working single lines, was one which left nothing to be desired. Mr. Hemans had found, from experience, that it was exceedingly defective; so much so that he was satisfied, unless great expense was occurred in doubling the lines, which the traffic on many railways would not justify, that it would be necessary to introduce the bell, or some other telegraph system. The Dundalk and Londonderry Company had a single line of 120 miles, and he had single lines to the extent of 75 miles. He had found, even when running only four trains per day in each direction, that it was next to impossible to repair defects on the line without working in the middle of the night, owing to the difficulty of getting the 'train-staff' from the passenger trains, for the use of the ballast trains, or even to run extra trains at times of fairs and markets. Under the 'train-staff' system a line might be shut up for hours, when under the telegraph system it might be usefully employed. Supposing a line to be divided into sections of 10 miles: a train would take twenty minutes to travel that distance, and during that time nothing else would be able to pass over that section. Further, there must be the delay of the train coming in the opposite direction, to bring back the 'train-staff' to the starting point. He was convinced that one, or other of these telegraph systems, when perfected, must be adopted, if ever the traffic upon single lines of railway was to be fully developed.

Captain Tyler, R.E., remarked, in reference to the working of single lines, that the train-staff had answered admirably in a great number of cases, both in England and Ireland, and that not a single accident had occurred, from trains meeting one another, where it was employed. On the other hand, where telegraph instruments had been used without a train-staff, there had been a number of accidents under various systems of working, in consequence of mistakes and misunderstanding on the part of the persons in charge of the instruments. Railway traffic was always liable to irregularity, and any system that could not be thoroughly relied on, under this condition, was not fit for adoption. When the time-tables could not be adhered to, it was frequently necessary that the crossing-places of the trains should be altered; and the station-masters then required, either to receive instructions, from a superior officer, and to convey them to others, or to arrange between each other as to those alterations. But station-masters were not always at their posts, and these arrangements were left, during their absence, to the porters, or other subordinate servants. It was in consequence of numerous accidents having taken place on different railways, that he had come to the conclusion, that the electric telegraph was not to be depended upon for the safety of the traffic on single lines. It was an admirable auxiliary for convenience, and no single line ought to be unprovided with it; but for safety he considered the train-staff alone ought to be trusted.

With regard to working double lines by telegraph, there were certain principles which should be observed in all cases; and those instruments ought to be adopted, which would allow of those principles being carried out in the most complete and efficient manner. With two lines of rails, there should be a distinct train-needle (or arm) for each line; and each train-needle should be used solely for saying either 'line clear' or 'line blocked' for the line to which it belonged. There should also be speaking instruments, to enable the men to communicate with each other, and thus to prevent their being tempted to use the train instruments for that purpose. Greater uniformity, than at present prevailed, was very desirable. He knew an instance in which four different systems of telegraph signalling were in charge of one man; and it was extraordinary how, under such circumstances, the traffic could be conducted with safety. When a junction was made between two lines on which different systems obtained, it became difficult to determine which should be adopted at the junction box, or station. Without venturing to express an opinion as to which was the best system, he might be permitted to say, that he thought the needle-instrument had, among others, a great advantage, in always showing when anything went wrong, provided the needles were kept habitually blocked over, either to one side, or to the other. When the needle assumed a vertical position, it was a sure indication that something was out of order; and no instrument ought to be used which did not at once indicate when there was any derangement.

Mr. E. A. Cowper believed no system of signals or telegraphs could ever be of the same importance, as careful and intelligent vigilance on the part of the guards and engine-drivers; and he felt bound to add his testimony to their general watchfulness. Still, if it were possible to increase, so to speak, their powers of hearing, and make them very long-sighted, so as to enable them to know at all times what was on the road two miles a-head, and practically to hear a train start from a station two miles behind, he thought it would be admitted that greater safety would be obtained, particularly having regard to the high speeds now so common, together with the usually deficient break power.

The long-established practice of working railways in Germany by telegraph, had been passed over in a summary manner in the Paper; for the Author had stated little more than that there were a number of bells and but few trains. Now the fact was, there was a considerable traffic on many lines, and although frequently consisting only of a single way, yet there were fewer accidents than on many double roads in this country. The system of signalling was not confined to bells, as one or more of the telegraph wires were devoted to regulate the trains, and generally on a 'block' system, so that a driver knew what was before him, and when a train started from a station behind him.

He might mention, that, in the year 1840, his attention having been called to the difficulty of signalling by a person on the road to the driver of a train, he had attempted, and perhaps with some success, to increase, practically at least, one of the senses of the driver; and as during a fog sight was of no avail, he had determined to try a definite appeal to hearing. After making several experiments on the Croydon Railway, by permission of Mr. Gregory, (V.P. Inst. C.E.,) then the Resident Engineer of the line, he succeeded in producing the Fog Signal, now so universally known, and he trusted, appreciated. It was only due to Mr. Gregory to say that, possibly but for his assistance, that simple little instrument might not have been introduced, and many lives might thus have been lost, and the traffic at times greatly interrupted.

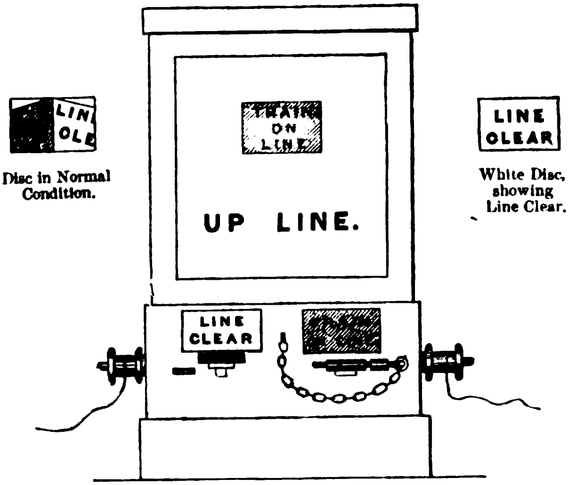
Mr. Adley could not allow the observations of Captain Tyler, with regard to the inefficiency of the telegraph in the working of single lines of railway, to pass unnoticed; inasmuch as in India about 2,000 miles of single lines (or considerably more than all the railways in Ireland put together) were worked by the telegraph, with comparative freedom from accident. During the not inconsiderable period, when he was in charge of the telegraph on the East-Indian Railway not a single accident had been caused by the system, though many had been prevented by it. If the telegraph had been the source of accidents on single lines in England, the failures must have arisen from mismanagement and for want of proper rules, rather than from any inherent defect in the system. Any accidents that had been imputed to the telegraph, as far as he could ascertain, were due more to the eccentricity of genius on the part of the railway officials, than to the system itself, when worked under proper guidance.

It was stated that 27 per cent. of the accidents in England were due to the want of the telegraph. As all the Indian railways had telegraphs, this percentage might be assumed to be erased from their quota of casualties. It would appear from the Parliamentary returns, that out of 4,225,240 passengers carried in India during the year 1860, none had been killed from causes beyond their own control, while ·94 per million only were injured. On comparing this with the English returns, it appeared that out of an annual average of 139,000,000 passengers carried 15 per million were killed, while 3·19 per million were injured. According to the latest returns, however, for the past year, the passengers carried were 173,721,139, while the number killed were ·26 per million, and 4·50 per million received injury. It also appeared that one-half of the accidents on the English lines arose from collisions, while on the Indian railways one-seventh only emanated from the same cause. This proved that collisions, which might be looked upon as preventible accidents, to a certain extent, were less frequent in India, and necessarily so, owing to the aid afforded by the telegraph in regulating the traffic.

Mr. Preece had stated that the telegraph was an uncertain agent, because of its mechanical arrangements. In this remark he could not altogether agree, as he had found it very reliable, amounting almost to a certainty, and the greatest confidence could be placed in it. Moreover, Mr. Preece, in his instrument, had a greater number of mechanical parts, which were so objectionable, and hence increased the liabilities to derangement; for in place of the direct action of a simple needle oscillating on a pivot, there was an indirect motion produced by a combination of levers. There did not seem to be any special advantages in the various instruments which had been exhibited: they were ingenious, and reflected credit on the inventors; but none were so simple, nor so efficacious for train-signalling purposes, as the common needle-instrument adopted by Mr. Edwin Clark.

Mr. T. Marr Johnson said, his particular attention had been directed to this subject, in reference to the train-signalling on the Metropolitan Railway. It was his duty as Resident Engineer, to examine most of the systems and instruments that had been referred to, as well as some others, but he did not feel entitled to pronounce upon their merits, as against the opinions of those who had made the matter a constant study. In the case he alluded to, it was considered necessary that, as so much depended upon the signalling, the system as well as the instruments should be simple and easy of comprehension by men of ordinary capacity, and that the instruments should be as little liable to mechanical derangement as possible. The instruments adopted on the Metropolitan Railway were the invention of Mr. Spagnoletti, and they had

Fig. 14.



Mr. Spagnoletti's Instrument, as used on the Metropolitan Railway.
Red Disc, showing Train on Line.

received the unqualified approbation of Mr. Fowler, the Engineer-in-chief of the line. In the normal condition of the instrument, when not in action, or in case of derangement, neither signal was distinctly visible. The line was blocked by pressing the red key, when the disc at both stations immediately showed the red colour, and the words 'train on line.' The colour indicated by the disc was always identical with that of the key upon which the finger was placed. The white disc signal was given for 'line clear.' Either could be seen from any part of the signal-box with a moderate light, and he considered that the marked distinction offered by the broad discs of different colours (red and white) constituted of itself an advantage over the needle signal. In this instrument when the battery became weak, the disc would show a narrow strip of an opposite colour, which increased with the decrease of battery power, and the weakness of the battery was apparent, long before it was of serious importance. The attention of the signalman was called by a bell. Supposing a train had just left A to go to B, the disc at A showing the white colour, B would receive a bell-signal of one stroke from A. At the same time the disc at B would be put over to 'train on line,' but not permanently fixed there. B would then reply by a return stroke of the bell, and by pinning down the red key, which would show a red disc both at A and B, and would indicate that no train was to be allowed to follow until B released it. B would always know by his own disc what colour was being shown at A; thus no effort of memory was required, and no mistake in the signals could be made. The Metropolitan Railway was worked entirely by telegraph; the trains being controlled by station semaphores, moved by the man at the disc instrument. During the three weeks that it had been opened, more than half a million passengers had been conveyed over the line; and on one occasion the passengers amounted to nearly forty thousand within fifteen hours. Some trains were run at intervals of four minutes, some at seven minutes and a half, and others at irregular periods, and no mistake had been made in the working.

Mr. Bramwell said, although he had not an intimate knowledge of the minute details of these instruments, nevertheless he believed he was sufficiently acquainted with the subject to appreciate when one instrument came in the guise of another. He could not help thinking, from the opinions which had been expressed, that the instrument of Mr. Edwin Clark was probably the best of all. Now, with reference to the system adopted on the Metropolitan Railway, he was at a loss to understand the distinction between it and Mr. Clark's, except that in Mr. Clark's instrument the needle pointed to the writing, and in Mr. Spagnoletti's the writing was moved by the needle. He thought the latter plan was objectionable, because in that case the needle was loaded with the surface containing the writing, and, therefore, had to move that surface, as well as itself, while in Mr. Clark's machine, the only matter to be moved was the needle, the writing remaining quiescent.

Mr. NEWMAN said Mr. Clark's signals were erected on the London and North-Western Railway in 1855, under his superintendence, and he had maintained them since that time. He thought the intelligence of the signalmen on railways had been underrated. On the London and North-Western line, they were supplied with magnets, with which they remagnetised the needles when required, and also with sulphate of copper, to recharge the batteries when they got weak. Those duties were performed with the greatest ease, and the instruments worked admirably.

Mr. JENOURE had had some practical experience on railways in the north of England, in Scotland, and in Ireland, as a Supervisor and District Engineer of Telegraphs, but he was not an advocate, or a partisan of any one method. The Author of the Paper urged the importance of having telegraph-signalling rooms wholly distinct. Such an arrangement might be advantageous, when liberal provisions allowed the constant attendance of steady and efficient clerks; but he rather held to an opinion he had formerly expressed, that the various telegraph methods should be generally taught in schools, so that when boys were taken into the service of a Railway Company, they might be able to work any telegraph instrument. He was in favour of the simplest forms of signalling, and held that the acknowledgment of a signal was indispensable, whether such response was by sound, or by a visible indicator. He thought the various alphabetical instruments might be adopted with advantage, because they placed the power of communication in the hands of station-masters, who had not learned the short-hand methods. On the Stockton and Darlington line,[1] the block system was maintained in a somewhat peculiar form, the whole of the mineral traffic being regulated by clockwork alarums. When a train left station A, a key was depressed which rang a bell at station B, and nothing was allowed to leave B until the train from A arrived there. Traffic might by this method be interrupted accidentally. He had once inadvertently touched a key at station A, which led station B to suppose that an unusual train had left, and the traffic from B to A was stopped, until it could be ascertained that the line was clear. This was an imperfect mode of signalling, because no opportunity was afforded of correcting a mistake. The frequency of trains in other parts of the country did not nearly approach the number on the lines about London, still on many lines the traffic was heavy. The Lancashire and Yorkshire Company's system of telegraph signalling, with Mr. Highton's single-needle instruments, was very complete, so far as regarded the breaking up into short circuits; and it was difficult to imagine how the trains would get on at all without the aid of electricity, for they were frequently behind time. That with care and punctuality a line might be worked without any electrical signals, was shown by the instance of the railway between Glasgow and Paisley, a length of 6 miles 7 furlongs. This line was the joint property of the Caledonian, and the Glasgow and South Western Companies. The former worked all the Greenock traffic over it, and the latter all the traffic to Ardrossan, Ayr, Dumfries, &c. There were two junctions, one tunnel, and one roadside station, between Glasgow and Paisley; both Messrs. Cooke and Wheatstone's, and Mr. Highton's instruments being employed, at Paisley and at the Glasgow terminus for ordinary messages. A year and a half ago he was consulted with reference to the adoption of some system of electrical signalling for trains on that line; but not being satisfied of the thorough efficiency of any mode then in use, the question was deferred. In reply to a recent inquiry, the manager of that line wrote, "We have not any electrical signals in the working of our traffic. In midsummer we had on an average one hundred and eighteen trains within nineteen hours, including up and down traffic. During five hours of the night the line was not occupied. For the greater part of last summer I wrought about one mile of the line as a single way while relaying. This was done under the Red Cap Pilot, and we had comparatively little delay, and no accident." He could bear testimony to the value of electrical signalling as an economical measure, even in its most expensive form, particularly in the case of long tunnels, where the costly use of pilot engines must be resorted to, if the wires failed only for a short time. In these days of ingenuity and diversity of opinion, the uniformity of system, which had been advocated, was scarcely practicable, however desirable it might be; but a wide field was open for labour and for improvement, and he agreed with the Author of the Paper in wishing, that railway authorities would take up the subject more earnestly and zealously than heretofore.

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[1] Mr. Thomas MacNay, Secretary to the Stockton and Darlington Railway Company, in a letter to the Secretary Inst. C.E., dated January 19th, 1863, relative to the plan adopted in working that line, says—

"All passenger trains are telegraphed by the 'Bell telegraph' from one station to the other; that is, as soon as a train has left a station, the telegraph signal is given to the next station, and that station is to reply, so as to make it known, that the signal has been recognised. Any neglect or omission to reply, is reported to the Superintendent. On any part of our railway which is a single line, we work by the 'staff-system,' and cause a regular message to be sent from one station to the other, stating that the passenger train has left, and the station answers that the message has been received."

Mr. Preece, in reply, observed, that he thought there could scarcely be any difference of opinion as to the necessity of the Paper. The discussion had been very full and free, and an amount of information had been gathered, which might not otherwise have been obtained. He regretted the narrow views which had characterised some of the speakers, who appeared to be so impressed with the importance of their own systems, as to ignore the general questions that had been raised. If he had failed to place Mr. Tyer's and the needle systems in the foremost rank, he had given reasons for not doing so; and if he had not considered the South-Eastern bell-system as the best, it was because he believed it to be the worst. When the Paper was perused dispassionately and quietly, he was convinced it would be found, that he had described, fairly and correctly, every system referred to.

He would now take a broad view of the subject, and would deal rather in generalities than in particularities. The first great question that arose out of the Paper was, the advantage of the general adoption of the telegraph in the working of railways. He was gratified to find, most of the railway managers who had spoken confirmed the opinion, that the telegraph was chiefly valuable as an auxiliary agent, and that its use should never be resorted to, until experience had shown its employment to be imperative. Mr. Eborall alone had advocated the adoption of the 'block' system. Mr. Preece believed that this subject had not been thoroughly considered, nor had Railway Companies arrived at any definite conclusions, as to the point of demarcation, where it was necessary to abandon the 'time' system and to seek the aid of electrical signals. The South-Eastern Railway Company used the block' system on their branches, where trains were few and far between; while a contiguous railway, the South-Western, continued to work the traffic on a very busy portion of their line (the Richmond branch) without the aid of the telegraph. The London and North-Western Company worked the length between London and Rugby by the aid of the telegraph, while between Manchester and Liverpool, where the trains were much more frequent, there was no electrical signalling system at all.

But it was upon single lines that the adoption of the telegraph was most urgently needed, and on this point he regretted to be at variance with Captain Huish, who advocated the use of the train-staff, to the exclusion of the telegraph. Captain Huish preferred delay, to the probability of accident from mistakes in messages. Captain Tyler had also supported the train-staff system, but Mr. Hemans had pointed out its failure on the Irish lines. The experience of the staff on the South-Western Railway was by no means in its favour. It frequently happened on the Epsom and Leatherhead line, that a man had to be sent on horseback, or by carriage to the other end of the line to obtain the staff. Wherever human agency was employed, there was always a liability to error; and it had even happened that an engine-driver had left without the staff. The telegraph was unquestionably liable to mistakes, but by the system employed on the South-Western Railway, it required three different persons to make three similar mistakes before any chance of accident could occur. The train-staff system might be very good in theory, but experience, which after all was the true test of theory, had shown it to be impracticable. The Board of Trade had issued a code of instructions, prepared with considerable care, for the use of the train-staff; but no such regulations had ever been circulated for the proper working of the electric telegraph.

Having thus determined that, in certain localities and under certain circumstances, a system of electrical signalling was essential, the question arose, as to whether that telegraph was to be dependent upon the organs of sight, or upon those of sound. It seemed scarcely necessary to those who were in the habit of using apparent signals, to argue this question; but when the South-Eastern, the London, Chatham, and Dover, and the North-Eastern Railway Companies employed bells, it was essential to inquire into the matter. Now the only argument advanced against the use of visual signals was that adduced by Mr. Walker, who contended that the deflection of a needle contained a contradiction in itself; as in reply to the question, 'May I send a train?' it said, 'Yes, you may not.' Nothing could be more absurd than this. The lowering of a semaphore was not a contradiction, and every engine driver who whistled down a signal considered it to be an intimation that he might proceed; and the deflection of a needle was taken to imply, 'Yes, train may proceed; line is clear;' and could not possibly be misinterpreted, as had been suggested. Mr. Walker himself had been obliged to resort to the use of indexes upon his recent bells. Several facts were instanced, exemplifying the confusion arising from the constant repetition of the same sounds, and he thought that a signalman in a small hut, surrounded by bells continually ringing, would be likely to get confused, and to neglect his duty. The London, Chatham, and Dover Railway required twelve beats of the bells to signify 'all clear,' and ten to indicate 'danger.' Such elaboration and repetition might conduce to safety, but only at the expense of simplicity. He contended that the weight of the evidence was in favour of visual as against aural signals.

The next point to be determined related to the advantage of producing these visible signals, either in a permanent, or in a transitory manner. As the use of transitory signals necessitated the employment of record books, he believed them to be disadvantageous, inasmuch as record books could never be trusted. Captain

Tyler remarked, in his report upon the collision between two trains near the Victoria (Pimlico) station "These entries [in the record book] would, if they were to be relied upon, confirm in a satisfactory manner the evidence."[1] Record books were undoubtedly useful, but they should be avoided as much as possible. Distant signals required no such entries, and electrical signals were nothing more than distant signals. Mr. Culley had instanced a case where the signalmen themselves had resorted to an expedient to obtain this permanent effect; and as experience had thus shown its utility, practice should confirm its necessity.

To determine the question, whether these permanent signals should be obtained by the use of continuous, or by momentary currents of electricity, it was necessary to refer to various natural and artificial phenomena which disturbed the correct working of telegraphic circuits. The first and greatest enemy to be contended with was the effect of atmospheric electricity. A flash of lightning might itself directly enter the wires, and completely destroy any telegraph instrument through which it passed; and in this respect every instrument which had been described suffered alike. But its most frequent effect was one resulting from the inductive action of a cloud charged with electricity, which might be passing at a distance even of several miles. Such inductive effect invariably took the form of a current, at one time so strong as to reverse the magnetism of the needles it traversed, at another abstracting the magnetism out of the needles, and at other times acting simply like an ordinary current, as though transmitted from a battery. Such effects were comparatively harmless on the semaphore, were easily remedied upon the needles, but were highly dangerous, as giving false signals, on Mr. Tyer's and other instruments worked by momentary currents. The liability of Mr. Tyer's instrument to be affected by lightning had been denied; but in a letter he had received from an inspector who had made inquiries on a line running out of London, it was said 'that they were sometimes affected by lightning.' Mr. Gilbert, the Telegraph Company's inspector on the Great North of Scotland Railway, also wrote as follows, on the 21st November, 1862, in reference to Mr. Tyer's signal system :—

"During the prevalence of lightning the permanent magnets sometimes lose the whole of their magnetism, and sometimes only that of one pole. In the former case the needles drop between the two poles of the magnets, and are useless for any signalling purposes. In the latter,[2] the needles adhere to the poles of the magnets in which magnetism exists, and if shifted by the line current to the opposite pole, will not remain but fly back. These defects are well known to the station agents, and when existing, they are guided by the beat of the bell or gong. Thus, if A has a train for B, he gives two beats on B's bell, which is tantamount to the question, 'train waiting, can it come on?' If line clear, B returns one beat on A's bell, and at the same time directs his own and A's needles to 'train on line.' The beat of the bell is therefore a guide, in the event of the needles being affected by lightning. If both bell and needles fail, as is sometimes the case, or any doubt exists, the trains are signalled by needle telegraph. It rarely happens that the poles of the magnets are reversed. Deflections, when strong, shift the needles and ring the bells, particularly in the old make of instruments. In the new instruments this defect is lessened, but still exists. The system is too complicated to allow of any local remedy being applied, in any case of interruption; thus a considerable time must elapse in the setting right of only a few stations. On a line like the Great North of Scotland, where the trains are few and far between, and where a needle telegraph exists to fall back upon, these defects are of comparatively little moment; but on a crowded line, where illiterate pointsmen are employed, and where no needle telegraph exists, confusion must arise, and I cannot see how any such line could be worked with safety. The system works well in the winter, and is, perhaps, then preferable to any other; but in the summer our own system is far safer, and I would give it a decided preference."

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[1] *Vide* "Reports of the Inspecting Officers," &c., 1860. Page 89.

[2] Mr. Gilbert is evidently in error in this. A magnet cannot be deprived of one pole alone. The effect is due to residual magnetism,—a peculiarity of electro-magnets alluded to by Mr. Fleeming Jenkin.—W. H. P.

He thought this evidence was conclusive, as to the liability of these instruments to derangement from atmospheric electricity.

Another natural phenomenon—that commonly termed 'deflections' or 'earth currents,'—seriously affected circuits worked by momentary currents. At certain times and seasons, immense masses of electricity passed through the crust of the earth, from the equator to the pole and vice versâ, traversing the telegraph circuits in their course, and causing great annoyance and trouble. In the needle and semaphore instruments, such currents produced little effect, as they rarely if ever equalled in force the usual working currents; but upon instruments worked by momentary currents, such effects produced a complete stoppage. The signal in Mr. Tyer's instrument in place of remaining at 'train on line,' would instantly fly back and remain at 'line clear.' Mr. Gilbert's letter afforded evidence of the effect of these earth currents.

There were also interruptions arising from accidental and artificial causes. The wires might be brought into temporary contact by the wind, or, as they frequently were, by the long levers of the platelayers; and cases had been known where birds alighting upon wires had produced similar effects. Such accidents would produce false signals on instruments worked by momentary currents, while those actuated by continuous currents would remain unaffected. An accident which occurred on the London, Brighton, and South Coast Railway, near the Victoria Station, on October 16th, 1860, was believed by the Author, who investigated it shortly afterwards, to be due to this cause. Capt. Tyler said,[1] "There is no question in this case of any irregularity in the working of the instruments or of the needle having been pushed over accidentally at the Victoria Junction, (which might possibly have happened under other circumstances in consequence of the instruments being as yet unprovided with glass covers,) because the statements of Bicknell and Agent are to the effect that they both saw the needle go over, and both heard the bell ring at the same time, though they could not be sure as to whether it rang three times or not." This was an illustration of the danger of depending upon sound.

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[1] *Vide* "Reports of the Inspecting Officers," &c., 1860. Page 90.

False signals were also produced on Mr. Tyer's instrument, by a defect which was pointed out by Mr. Fleeming Jenkin, whereby a signalman, to make the same signal, had at one time to push one button, and at another time the other button. Evidence of the occurrence of such a false signal was given in a letter he had received from a late inspector of his, who said:—

> "The wrong signal that was given on Tyer's instrument at * * * * the other day was caused by the man pressing the wrong piston, and was likely to have been very serious in its consequences; but the affair has been hushed up; and Mr. * * * seemed very reluctant in giving me any information about the instruments, but said they are sometimes affected by lightning."

He therefore contended that, judged by the liability to accident from natural and other phenomena, instruments actuated by momentary currents were decidedly inferior to those worked by continuous currents.

The question of the superiority of the various systems was consequently reduced to the relative merits of Mr. Clark's and of the semaphore. Presuming the defects of each to be equal, as a telegraphist, Mr. Preece would as soon use the needle as the semaphore, but as his object was to produce uniformity in signalling, he believed the semaphore to be fully equal to all the requirements of a railway. It had been contended that, inasmuch as the semaphore was a mechanical arrangement, it was defective; but all telegraph instruments were more or less mechanical arrangements, and while the construction of the semaphore was visible, if the interior of most of the instruments which had been described were examined, it would be found that they were considerably more intricate than the semaphore. It was absurd, in the present day, when mechanical construction was brought to such perfection, to object to an instrument on account of its construction, unless it was unduly complicated. In the instrument in question, there were only two pivots, one lever, and a rack and pinion. It was questionable whether any other instrument was so simple. Moreover, the simplicity of its construction rendered it peculiarly suited for the hands of uneducated signalmen, who fully and completely comprehended it, from their acquaintance with the construction and working of the out-door semaphores, with which it was assimilated in every particular. The intelligence of signalmen had been much underrated, as Mr. Newman had pointed out, and experience had fully shown, that when an instrument which they understood was placed in their hands, it received as much care and attention as if the men were skilled mechanics. It was infinitely preferable to place such an instrument in the hands of signalmen, than to give them an instrument kept invariably under lock and key.

Again, it was contended, that the semaphore arrangement was not new. If he had felt any curiosity before the commencement of this discussion, it was to know how many claimants there would be for the invention of the semaphore. He had, therefore, been agreeably surprised to find there was only one such claimant. He did not conceive the mere inventor of a useful article to be the only one entitled to credit; those who brought it into general use surely merited some notice. It was not Mr. Cooke who invented the telegraph, but he introduced it, and was therefore deserving of the reward he had received. He willingly accorded to Mr. Walker any reputation that might accrue from originating such an instrument, but of which Mr. Preece had been perfectly ignorant when he brought out his own; but if such a really useful thing had been allowed to lapse for a period of nine years, it certainly should not now be brought forward, in order to attempt to detract from the credit due to its introducer. The idea conveyed in the two instruments was similar, but their mechanical construction was totally different; and while Mr. Walker's was a simple needle, in no way differing from an ordinary needle instrument, but with its defects magnified, Mr. Preece's was to all intents and purposes a practical railway signal, based upon a totally different principle. Both Mr. Walker and Mr. Preece had, however, been anticipated by Mr. Ward, who, in 1847, invented and patented a semaphore worked by electricity; but he went beyond either by fixing the semaphore visibly before the driver on the line. It was not however the mere invention of the semaphore that Mr. Preece claimed; it was the assimilation of the electrical to the ordinary line signals of the particular railway upon which they might be fixed, the method by which electrical signals were simply worked as distant signals, and the reduction of the whole system to one uniform plan. This had never been attempted before. Allusion had been made to the effects of decreasing battery power. Now, upon no instrument was the failing strength of the battery shown more clearly than upon the semaphore, the arm of which rose with greater or less rapidity, according to the strength of the current. It had also been stated, that five wires were necessary to work this system in its complete form. This was an error, as only four were required. In practice, however, three wires were used for a double line and two wires for a single line, as in the case of Mr. Clark's system. A single line could be worked by the semaphore system on one wire alone, but he deprecated the use of a single wire. It must also be observed, that in the event of derangement from any cause, either to the wires or to the instrument, the arm immediately showed the danger signal, and thus warning was at once given, and security obtained. In conclusion, he expressed a hope that the time might come, when all the great railways of the kingdom would be worked on one plan for the manifest advantage of all.

Mr. HAWKSHAW,—President,—said the discussion of this subject showed that electricians were still a long way from uniformity; and he was not sure if, at this stage of the inquiry, uniformity was desirable. It had been objected, on the score of safety, that there were too many trains on railways. He was afraid that objection would not be obviated, for, in his opinion, the number of trains would increase, as the growth of population, and the tendency of people to live near railways, must lead to the multiplication of trains. He felt that whatever science and vigilance could accomplish, to ensure greater safety on railways, should be done; and he thanked Mr. Preece for having brought forward a Paper which had elicited a great variety of opinions, as to the best mode of applying telegraphs to railways. He placed a high value on the opinions of Captain Huish, who had had such long experience on this subject; but he could not agree with him on one point. Theoretically, no doubt, the train-staff led to greater safety than any other mode of working. But persons might be preserved from railway accidents by not going upon a railway at all; and the train-staff system was an approach to doing away with railway travelling. As a system, it simply meant that, provided a Company confined itself to one staff, it would also limit itself to one locomotive; and so long as only one locomotive at a time ran upon the line there could not be any collision. But it was obvious that, under that system, trains could not be started from the same end of the line at short intervals of time; as when the staff was at the other end, it must be brought back, and this necessarily involved delay. He considered the train-staff system was wholly inapplicable to any railway on which the traffic was large. Neither could he concur with the remark, that a great mistake had been made, in not more generally adopting single lines of railway; or that, with the use of the telegraph, proper superintendence, and due vigilance, a single line of railway could be made as useful as a double line. If an accident happened upon a single line, the traffic of the whole system was stopped. Therefore, although there were cases in which single lines were proper, inasmuch as the district might not afford sufficient traffic for a double line of rails, yet he should not wish it to be understood, that one line of rails could ever answer all the purposes of two lines.

As to this particular question, he concurred with those who thought, that every one engaged on railways should always be on the alert, and that nothing should be done to diminish, or to relax, the vigilance of the engine driver, in looking out for the signals during his journey; but, so far as he knew, he did not believe the tendency of telegraphic arrangements had produced that effect.

With regard to the electric telegraph, he had on previous occasions expressed his opinion of its great utility. It was adopted about the same time that railways were introduced; and to those who aided in its establishment, society at large owed a great deal. There was one point of view from which the telegraph became very important: whatever time might be saved by railways, the telegraph carried that reduction still further. Here the train-staff failed. If, for instance, A wanted something from B, by employing the telegraph, B could be instantaneously informed of this want; whereas without the telegraph a message must be sent by an engine to B, to bring back what A required. The same advantage would be conferred upon steam-boat communication by the electric telegraph. Whatever might be gained by the time saved in transit by steamers, the telegraph would double the saving. Merchants requiring goods could ask for them by telegraph, and the steamer could be loaded and dispatched at once. Without the telegraph, the steamer must go one way to announce the want, and return back again to supply it. Although it had not been proved, whether Mr. Tyer's, or Mr. Preece's, or Mr. Walker's system was the best, he believed that all were calculated to be of advantage to railways. The telegraph would be of great service, and must ultimately become essential in working railways, though clouds charged with electricity might occasionally demagnetise the needles; and he hoped those gentlemen who had undertaken that branch of science would continue their endeavours to eliminate, as far as possible, every source of error.

January 20 and 27, 1863.

JOHN HAWKSHAW, President,
in the Chair.

The discussion upon the Paper, No. 1,079, "On Railway Telegraphs, &c.," by Mr. W. H. Preece, was continued throughout these evenings, to the exclusion of any other subject.

Railway Break.

After the Meeting a model of a Railway Break was exhibited by Mr. W. G. Creamer, of New York. This plan was stated to embrace, first, an arrangement of compensating, or balanced breaks, worked by one lever, and distributing the pressure equally on all the wheels, with a small expenditure of power. Secondly, an attachment of reserved power to the breaks of every carriage, in combination with a non-elastic signal rope, so as to enable the driver instantly to apply every break in case of danger; or on the separation of the train, or any part being thrown from the line, the breaks would apply themselves automatically, as each carriage was entirely independent of all the others, and the breaks were available wherever they were placed in the train.

February 3, 1863.

JOHN HAWKSHAW, President, in the Chair.

The following Candidates were balloted for and duly elected:—EDWARD FILLITER, and ARTHUR SIDNEY ORMSBY, as Members; THOMAS EDWARD DUNN, JAMES ROBERT FURNISS, Captain JAMES GRANTHAM, R.E., JOHN JACOB HOLTZAPFFEL, STEPHEN LANCELOT KOE, ALFRED STANSFIELD RAKE, LEONARD ROBERT ROBERTS, ROBERT OWEN WHITE, and HUGH WILSON, as Associates.

No. 1,048.—"On the Woods used for Sleepers on the Madras Railway." By BRYCE M^{c}MASTER, M. Inst. C.E.

OF all the questions relating to the construction of railways in India, there is not one of greater importance, and few have of late years received more consideration, than that of the substructure of the permanent way; and most deservedly so, for it has a material influence on the cost of maintenance of the line. The native wood sleepers having hitherto been found, for the most part, deficient in durability, attention has been turned to an iron substructure for the permanent way; and as the resources of India seem inadequate to meet the demand, the question has arisen, whether sleepers of cast iron, or of creosoted timber, must not be sent from England? This is so important, that it is desirable to inquire into the causes of the failure of the native woods, with a view to ascertain whether these causes can be overcome, and the vast resources of the country be rendered available.

On the Madras Railway between 30 and 40 per cent. of the sleepers have annually required renewal. This has been due to two causes: first, to the employment of woods unfit for the purpose; and secondly, to the sleepers being cut from young trees, which would have been good if allowed to stand till old enough. With reference to the first of these, it was to determine which woods ought to be rejected as unfit for sleepers, at whatever age they might be cut, that the Author, in the year 1858, commenced a form of examination which should discover and record the annual deterioration of the sleepers. It may appear a simple matter to note the names of the woods as they were removed, and to discontinue the use of such as were found to be unsuitable; but experience showed that, in the majority of instances, the sleepers decayed so rapidly and so completely, that it was impossible to determine, with any degree of accuracy, the names of the woods. The nature and appearance of the woods were often entirely changed, and all brands, or other marks made on the sleepers when new, were effaced. In practice the Author prepared a list of upwards of thirteen hundred sleepers, on a portion of the line convenient for the purpose, and numbered these sleepers from certain fixed points. They were examined carefully twice, at an interval of twelve months, and the state of each sleeper, at the date of the examination, was recorded. When decayed sleepers were met with, it was easy, by reference to the list, to discover what the woods were. The Author's sudden departure from India prevented a third annual examination, and his observations are, therefore, less calculated to prove the length of time good sleepers will last, than to show those which should not be used at all in a plain state,—a point on which, as far as he is aware, no system had previously been adopted, and the want of which information had caused many woods to be used for sleepers, which were proved by the Author's first examination not to be capable of enduring a single year.

The sleepers examined were variously placed—some on embankments and some in cuttings. Advantage was also taken of the opportunity to test the effects of different forms of ballasting, regarding which there had been some discussion amongst the Engineers on the line. The system usually adopted on the Madras Railway was to cover the sleepers entirely with ballast; which, outside the rails, was on a level with the tops of the keys, and between the rails was about 4 inches over the sleepers. This was drained in the ordinary way, by cross drains at intervals. The other system, which was adopted by the Author on the division under his charge, was to leave the sleepers as much as possible uncovered. In the middle, between the rails, the ballast was raised about 2 inches, and it was sloped off so as to throw the water under the rails; the sleepers from the rails to the outer ends being uncovered.

The annexed statement gives the Tamil and the botanical names of the woods which came more particularly under observation, with the state of the sleepers at the end of the second year:—

Tamil Name.	Botanical Name.	Uncovered.			Covered.		
		Good.	Serviceable, but beginning to get bad.	Useless.	Good.	Serviceable, but beginning to get bad.	Useless.
		Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.
Chella woonjay	Acacia odoratissima	63	29	8	55	33	12
Vel vengay . .	Ditto speciosa . .	37	36	27	17	36	47
Dud eloopay .	Bassia longifolia. .	60	25	15	64	25	11
Vella naga . .	Conocarpus latifolia.	47	29	24	20	..	80
Miladi . . .	..	6	6	88	..	..	100
Margosah . .	Melia Azadirachta .	43	43	14	..	25	75
Kurkuttah . .	Zizyphus glabrata .	..	31	69	20	10	70
Kurrah murdah	Terminalia glabra .	66	28	6	35	31	34
Palay (red) .	Mimusops hexandra	75	25	..	38	62	..
Kotvoye . .	Acacia speciosa . .	46	8	46	7	30	63
Maroothy . .	Terminalia alata .	13	28	59	29	15	56
Coombaderie .	..	22	22	56	7	11	82
Auray . . .	..	..	9	91	9	12	79
Karavalum . .	Acacia Arabica . .	80	20	..	56	22	22
Necanee . .	Conocarpus latifolia	11	22	67	..	..	..
Cadookoy . .	Terminalia chebula.	..	..	..	11	16	73

From this table it appears, first, that only five woods—the Chella woonjay, Eloopay, Kurrah murdah, Palay, and Karavalum—were sound at the end of two years, and that the other eleven species would not last as sleepers for that time. Secondly, it is evident, that where the sleepers were uncovered, decay was much less rapid than where they were completely buried in the ballast. The last two woods in the list were not found in the two systems of ballasting; of the remaining fourteen it will be seen, that in ten the advantage is decidedly in favour of the uncovered sleepers, while in the other four, the difference in favour of the covered sleepers is extremely small.

The system of leaving the sleepers as much as possible uncovered has many advantages. It effects a saving of about 9 cubic yards of ballast per chain of line, and there is proportionately less labour in opening out the road for examination, or repairs. It allows the platelayers to detect at once any defects in the substructure of the road, which, when the sleepers are buried in ballast, can seldom be done, until the effects are visible in a depression of the rails; and by throwing off wet more rapidly, it keeps the sleepers drier, and induces their better preservation.

The objections urged against the system were, that the heat of the sun would split the sleepers, and cause the keys and trenails to shrink. Further, that the road would not be sufficiently bedded in the ballast to prevent its twisting when the rails expanded, or on the passage of trains.

Regarding the splitting of the sleepers, the following statement, referring to the whole of the sleepers examined, shows the effects of the two systems:—

	Good.	Beginning to split.	Beginning to rot.	Useless; split.	Useless; rotten.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Uncovered .	47	19	8	2	24
Covered . .	38½	12	13	.	36½

It thus seems that, while amongst the uncovered sleepers there is a larger proportion 'beginning to split' or 'useless from being split,' there is, on the other hand, amongst the covered sleepers, a still larger proportion 'beginning to rot,' or 'useless from being rotten;' and the per centage of good sleepers amongst the covered is less than amongst the uncovered. On the whole, therefore, it appears to be decidedly better not to bury the sleepers in the ballast, as has generally been done. As regards the trenails, the Author found that where the sleepers were rotten the trenails were almost invariably rotten too, on which account uncovered sleepers seem to be preferable. On the other hand, he never found that trenails whose heads were exposed to the sun were loosened by shrinking. Keys, if not properly seasoned, will shrink in India. No system of ballasting which would protect them from the sun would be admissible, as it would effectually prevent the platelayers from tightening them up. Besides this, the Author found, that where the ballast touched the keys, whether of English, or of native wood, they were generally soft, and covered with fungus, and, where the line was not opened for traffic, in many instances they were eaten by white ants. With reference to the last-named objection, that the road would be more liable to twist and buckle if the sleepers were not buried in the ballast, the Author can only state, that he never knew this to be the case on 40 miles of line thus ballasted and opened for traffic, on the division under his charge.

Trenails made in India cost from £2 10s. to £4 per thousand; the price varying with the difficulty of getting wood and labour. The woods generally used for the purpose were the Vengay, Kurrah murdah, Erool, Porasa or Satin wood, and Trincomalee. These trenails appeared excellent, but the Author left India before he had an opportunity of observing their durability. He is, however, convinced, that they are equal to any trenails sent from England. Trincomalee wood in particular seems deserving of more attention for the manufacture of trenails. Keys were also extensively made in India, of the Vengay, Kurrah murdah, Erool, and Teak. These keys were considerably longer than usual, so as to allow of their being driven up, when theygot loose. Teak keys seemed to be the best, and as their cost did not exceed £6 per thousand, it would be worth while to have them supplied in India. The other woods named, if properly seasoned, would doubtless be found as durable as, and cost less than, Teak.

From personal observation and inquiry, the Author thinks the following twelve woods will make really good sleepers, to be used plain:—

TAMIL NAME.	BOTANICAL NAME.
Teak	Tectona grandis.
Saul	Vatica robusta.
Sissoo	Dalbergia sissoo.
Pedowk	Pterocarpus Indicus.
Kurrah murdah	Terminalia glabra.
Aucha	Hardwickia binata.
Vengay	Pterocarpus marsupium.
Chella woonjay	Acacia odoratissima.
Erool	Inga xylocarpa.
Karavalum	Acacia Arabica.
Dud eloopay	Bassia longifolia.
Palay	Mimusops hexandra.

The previous list contains the names of eleven woods which should, in the Author's opinion, be rejected as unfit for sleepers, if used in a plain state.

It is deserving of notice, that of the sleepers 'beginning to rot' 19 per cent. of the whole had begun under one, or both chairs. In many of the sleepers which were so rotten as to be useless, it was impossible, from their state of decay, to determine where, or how the decay had commenced. Speaking, therefore, only of those previously alluded to as 'beginning to rot,' the additional fact was observed, that in the uncovered sleepers 24 per cent., and in those covered 18½ per cent., decay had begun under the chairs. The Author believes that the cause of this decay is the retention of moisture under the chairs, in the hollows of the castings. The rarefaction of the air within this hollow would be greater when the chair was not protected by ballast from the heat of the sun: when rain fell, this air would be sooner cooled, and the water would have freer access to the interior, than where ballast intervened. It may be said, that under any circumstances the quantity of water so retained must be extremely small. Nevertheless for many hours after the rest of the sleeper was perfectly dry, damp was observed all round each chair, the water within being slowly expelled, as the chair was again heated. The large proportion of sleepers shown to have been affected by this damp, and the fact that many sleepers had to be removed, because they were rotten under the chairs, while the rest of the sleeper seemed perfectly good, are sufficient proofs that this subject deserves consideration. It is believed that if the seats of the chairs in the sleepers were well tarred, it would go far to remedy this evil; although the Author had not an opportunity of witnessing the effects of what he recommends. It cannot be said that the chairs had, in any instance, been crushed into the sleepers, for at the date of the second and last annual examination, nothing heavier than a platelayer's 'trolly' had passed over them.

With regard to the second cause of failure,—the woods being used too young and unseasoned,—the list already given, of the state of the sleepers at the end of the second year, does not show the actual expenditure of sleepers on the Madras Railway up to that time. Large as the renewal is there seen to be, it was even yet larger in reality. For as the main object of the investigation was to discover what woods were good and what bad, so in the record made of the results of this investigation no notice was taken of the decay of sap wood, which unfortunately formed a considerable portion of many sleepers; its decay, which took place always before the end of the first year, leaving so little of the original sleeper as to necessitate its renewal. In such cases when the heart wood was found to be sound and good, the sleeper was recorded under that head.

The circumstances under which the sleepers were supplied were such as to account, in some measure, for the great loss from this cause. In the first place, until sleepers were actually required for the railway, there had not been any demand for them from any quarter. The jungles were unknown to all but a few native wood-cutters. A commencement was made by some of the civil servants of the Government, who rendered valuable assistance to the Railway Company, by working the jungles in their neighbourhood. The example thus set was followed by natives possessed of capital, who entered into contracts with the Railway Company for the supply of sleepers. These men sublet the work to 'wudders,' a peculiar tribe accustomed to wood-cutting in the jungles. But this arrangement was speedily found to fail. The native contractors took little interest in the work, and exercised little supervision over the wudders. They secured themselves by throwing upon the wudders, a poor ignorant race of men, all the loss caused by sleepers being rejected by the Railway Company's agents. The want at that time of any supervision in the forests, (now ably exercised by the Forest Department), tempted these wudders, and the rude appliances at their command forced them, to leave untouched large trees from which really good sleepers might have been cut, and to satisfy themselves with felling only the smaller and young trees. They also frequently lopped off the branches of large trees, and left fine trunks standing. Of course a large proportion was rejected by the Engineers of the Railway Company, but the supply was so scanty and irregular, that at last, when the permanent way was being laid, sleepers had to be obtained by any means, and many sleepers which would have been rejected at first were bought up eagerly at last. In fact instances occurred, in which sleepers rejected by one Engineer, who could afford to pick and choose, were taken immediately to a less fortunate neighbour, (the marks of rejection branded on them being carefully removed), and by the latter they were bought and used. Under these circumstances it is not to be wondered at, that so many inferior sleepers were used. The appointment of Conservator of Forests was made in December 1856, but some time elapsed before the arrangements could be completed for an efficient supervision and systematic working of the forests. It was not, for instance, until July 1858, that an establishment was sanctioned for the working of the Salem Jungles, from which a large portion of the railway was supplied with sleepers. Things continued in this state until May 1858, when the system of giving large contracts for sleepers was discontinued, on account of the utter inability of the contractors to fulfil their engagements, and the Engineers received permission to purchase sleepers direct from any one who should offer them for sale. This change had many advantages. The middle-men being done away with, the Engineers had direct access to the wood-cutters. In many cases the price of the sleepers was reduced, but where it remained the same, the wood-cutters who brought the sleepers direct to the Railway Company received a larger profit, than when they had to work for contractors who were not remarkable for liberality, nor even for honesty in their dealings with the poor, ignorant labourers. But many of the disadvantages of the old system still continued. The different establishments of the Forest Department were at first unable to superintend and control the numerous parties engaged in all directions in felling timber, and the wood-cutters were still no further advanced in the knowledge of the good woods, or the means of obtaining proper appliances for felling any but the smallest trees. The results were, therefore, although in a less degree, the same as before. Sleepers were used green and unseasoned. The supply of good sleepers was far short of the demand, and timber of inferior quality had to be bought at last, to complete the laying of the permanent way.

From what has been said, it will be seen that the sleepers which have failed on the Madras Railway may be divided into two classes:—those which are of perishable woods, and those which, although of good woods, have been cut from young trees. The existence of the first is to be attributed to want of experience of the nature of the Indian woods; and of the second to want of a proper system in working the jungles. It is of importance to consider how far these evils may be remedied. As regards the first, experience is being gained every day of the woods suitable for, and actually used for sleepers, and if those who have opportunities of witnessing their durability would record the result of their observations, much useful knowledge would be gained, and economy might be effected in the construction and maintenance of Indian Railways. It is indeed hardly possible to suppose that, after so many years' experience, there has not been much information obtained in all parts of India, regarding the nature and qualities of its timber; but it is to be regretted, that hitherto no means have ever been taken to collect such information, or if collected, to disseminate it, so as to render it useful to the Railway Companies.

The two systems of procuring sleepers, through native contractors possessed of capital, and by purchase direct from the wood-cutters, or others, having been found to fail, the question arises, What can be done to secure a plentiful supply of good sleepers? The Author is persuaded, that this will be accomplished when, but not until, the Railway Companies send their own agents, with sufficient establishments, into the jungles, to cut down the wood themselves, to furnish the wood-cutters with proper appliances, and personally to superintend their operations. This was done on the Madras Railway, in one or two instances: in particular in the Paulghaut Jungles, where Mr. Ross, the Resident Engineer, (afterwards the Chief Engineer of the Madras Railway,) worked the jungles systematically. The result was, that Mr. Ross was able to furnish from his own resources nearly eight districts; while on portions of the line where the other systems were in operation, the supply required for one district (of 25 miles) could not be obtained from some scores of suppliers. In the case of a new line of railway, it would be highly desirable, as soon as it is settled that the line is to be made, to send establishments into every jungle, and to commence felling really suitable timber. Then by the time the sleepers were required, the logs would be tolerably well seasoned, and they might be cut up into sleepers and be conveyed to the works. There is no doubt that the cost of these establishments would be money well spent; for besides the immediate advantage of a large supply, and the ultimate advantage of the sleepers being of good and seasoned woods, it is certain that the cost of the sleepers might be reduced, as large profits seem to have been made by the native contractors. The present practice is to push on the earthworks and masonry; and too often when these are ready to receive the permanent way, there is not a sufficient number of sleepers, and the Engineer is obliged to buy any timber he can get. Directors and shareholders are satisfied for the time, and when, after the first year, they hear of the extravagant cost of renewals, the Indian jungles are condemned as unfit to yield the required supplies, and England is resorted to for a substitute, without sufficient thought being given to the want of experience and system which must operate at first.

So far, reference has only been made to such Indian woods as may be expected to answer if used plain, and to the means of obtaining them. But the Indian jungles abound in woods which are of too perishable a nature to allow of their being used in that state. The Author thinks that the sleepers should be creosoted, or otherwise prepared, on a much larger scale than has yet been attempted; so as to render available many of the woods which would otherwise be useless. In a previous Paper,[1] allusion was made to the creosoted sleepers sent from England to Madras, and an opinion was given of their value. Shortly before his departure from India, the Author examined some thousands of these sleepers, both of the rectangular and the triangular cross section, which had been laid for four years, and the impression then formed was, that they were admirably adapted to the country. An exceedingly small number had been renewed. They had been laid, mixed with native wood sleepers, of the description usually supplied, and while the native wood sleepers had in two, or three years become so rotten as to be, with few exceptions, unfit for use, the creosoted sleepers were as good as when they were originally laid. It may be stated, that the cost of an English creosoted sleeper conveyed, say, 100 miles by rail and 50 miles by road, would be nine shillings and sixpence, while the average price of native wood sleepers used plain and delivered on the works was six shillings each. The English creosoted sleepers are liable to get too dry from exposure to the sun, especially those of a triangular cross section, which are apt to be broken at the edges in being laid. All creosoted sleepers should be constantly protected from the direct heat of the sun, until actually required, and care should be taken in laying them. It is because English creosoted sleepers answer so well in India, that the Author recommends that native wood sleepers should be subjected to the same process. It is true that some sleepers have been so treated, both on the East Indian and on the Madras Railways, and possibly elsewhere; but as far as the Author is aware, the experiment has not been fairly tried. Saul, Teak, Soondry, Sissoo, and such other woods as have been creosoted, or otherwise prepared, and to which the experiment appears to have been limited, are all hard, durable woods, and so close-grained as to make it a difficult matter to force the solution into them. Why should the most expensive woods in first cost and those most difficult to creosote, be selected, when there are many others more plentiful and more easily obtained, lighter and more open-grained, and therefore more easily creosoted? Establishments and apparatus for creosoting, or otherwise pickling, might be erected in convenient positions near each extensive jungle, and such establishments would be more, or less permanently useful. Sleepers of common light woods might easily be procured at an average price of four shillings and sixpence each, delivered on the works; and, judging from what has already been done in India in this way, the cost of creosoting, including the expense of the apparatus, would probably be less than one shilling each. There is every reason to believe, that sleepers thus prepared would last as long as those sent from England, at one-third less cost.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xviii., pp. 417-422.

Having thus attempted to explain the chief causes of failure in the native wood sleepers, and how these may be overcome, in order that the resources of the country may be made available, the Author will now endeavour to show, that these resources are likely to prove sufficient to meet the demand. Taking, for example, one forest, that near Salem, out of probably twenty in the Madras presidency:—It is stated, in the Report of the Conservator of Forests for the official year 1859-60, that from the Salem jungles alone two hundred and forty-six thousand sleepers, or sufficient for 133 miles of railway, were cut during that year. Of course, a large number were rejected, and of those actually bought many were found to be very perishable; but the figures show what one forest can yield. As might be expected, it was not without considerable anxiety that those interested in the conservation of the forests saw the vast drain required to supply the railways. In the Report alluded to, the Conservator of Forests calculated that, for 1,150 miles of railway, sanctioned, or contemplated for the Madras presidency, an annual supply of two hundred and fifty-three thousand sleepers (say thirty-five thousand trees) would be required for renewals alone, allowing each sleeper to last on an average eight years. Arrangements have been everywhere made for planting good trees to meet this demand and to keep up the supply. With twenty forests from which to draw the supply, the demand on each would average about one thousand sleepers per month; and this does not appear above what may be expected from the supply. Railway Companies and other bodies likely to require large supplies of timber are recommended to plant on their own lands trees suitable to their requirements, a plan which, if followed, would much increase the sources of supply. But it will be many years before there are 1,150 miles of railway requiring an annual supply of sleepers, and the numbers given above are sufficient to allow of a renewal annually of about 25 per cent. of sleepers for some time to come.

The Author cannot discover, in the Reports of the Conservator of Forests, any information regarding the largest amount of timber that may annually be obtained from the Madras forests. Probably the short time the Department has been in existence, the limited number of assistants, and the immense amount of work they have had to perform, as well as the still unexplored state of many parts of the forests, have tended to prevent this information from being obtained, and without it no correct calculations can be made. But as a supply from each jungle of two thousand sleepers per month would provide for the construction of 500 miles of railway within the next five years, and for the same period would allow a renewal of 33 per cent. of the sleepers already laid, it may be confidently anticipated that the supply will not fail, if means are taken to make the naturally perishable sleepers last a reasonable time.

An analysis of the two hundred and forty-six thousand sleepers already stated to have been cut in the Salem jungles during the year 1859-60, may be useful, as exemplifying the waste of timber and the great expenditure of sleepers that then prevailed; and further it will be seen, how large is the number of sleepers which can be obtained, if artificial means are used for preserving those of a perishable nature. The sleepers referred to may be divided as follows:—

	Good.	Bad.
Known to be good . . .	82,000	..
Known to be bad , . .	..	96,000
Not known, of unsanctioned woods, and probably rejected.	..	46,000
Ditto, of sanctioned woods, allow one-half to be good .	11,000	..
Ditto, of sanctioned woods, allow one-half to be bad .	..	11,000
Totals . .	93,000	153,000

It therefore appears, that of these two hundred and forty-six thousand sleepers about 62 per cent. were practically useless. Surely then, when, of the sleepers which could be cut under ordinary circumstances, two-thirds cannot be used plain, no stronger proof is necessary of the importance of at once taking steps to turn these to account, in the only way in which it can be effected.

But after all, the great argument will always be, the comparative cost of each description of way; and the Author will therefore, before concluding, show the probable cost of one mile of single line of four different kinds of permanent way in the Madras presidency. In questions of this nature the cost of 'leading' should always be taken into consideration. In the following estimates, the cost of conveying the materials 25 miles up the country has been added:—

No. I.—WITH CAST-IRON SLEEPERS.

	£.	s.	d.
Rails, fish-plates, bolts and nuts, cast-iron sleepers, wrought-iron tie bars, gibs and cotters, and keys, delivered at Madras, per mile	2,065	0	0
Conveying 25 miles by carts, 262 tons at 6*d.* per ton per mile	164	0	0
Total cost per mile	£2,229	0	0

No. II.—WITH CREOSOTED SLEEPERS SENT FROM ENGLAND.

	£.	s.	d.
Rails, chairs, fish-plates, bolts and nuts, delivered at Madras, per mile	1,439	15	0
Conveying 25 miles, by carts, 164 tons at 6*d.* per ton per mile	102	10	0
Keys and trenails, native made, and carried 25 miles, per mile	47	0	0
1,584 English creosoted sleepers, delivered at Madras, each 7*s.* 1*d.*	561	0	0
Conveying ditto 25 miles by carts, per mile	100	0	0
Total cost per mile	£2,250	5	0

No. III.—WITH NATIVE WOOD SLEEPERS, USED PLAIN.

	£.	s.	d.
Materials and carrying as before, per mile	1,589	5	0
1,584 plain native wood sleepers, each 6*s.*	475	4	0
Total cost per mile	£2,064	9	0

No. IV.—WITH NATIVE WOOD SLEEPERS, CREOSOTED.

	£.	s.	d.
Materials and carrying as before, per mile	1,589	5	0
1,584 native wood sleepers creosoted, each 5*s.* 6*d.*	435	12	0
Total cost per mile	£2,024	17	0

From this comparison it appears, that English creosoted sleepers make the dearest, and native creosoted sleepers would make the cheapest road. It has already been stated, that as the creosoting, or otherwise pickling, of native timber has never been attempted on a large scale, it is impossible to say what the actual cost of sleepers thus prepared would be. The reason of a less price being allowed in these estimates for creosoted native sleepers than for plain native wood is that, to insure the duration of plain native sleepers for a sufficient length of time, a high price must be given for hard woods, whereas common soft woods for creosoting might be obtained at much cheaper rates. Owing to the heavy cost of carriage, the native wood sleepers present an advantage over the two systems in which English sleepers are used;—that is to say—an advantage in first cost, for, as regards the durability of the different materials, all the information gained in India up to this time is negative rather than positive. It is known that certain woods will perish within a certain time; but it is not known how long the best hard woods, or those artificially preserved, will last. No satisfactory comparison can therefore be drawn between the different systems of permanent way, as regards the cost of maintenance. It appears, however, that while the defects hitherto discovered in the native wood sleepers are pretty generally known and often dwelt upon, it is too frequently the practice to imagine that a cast-iron way in India possesses all the advantages claimed for it in England. In addition to the cost of freight and carriage, the cast iron 'pot' sleepers are not only liable to breakage on the voyage out, but also while being landed, and in their carriage up the country; and owing to the carelessness of the native workmen in unloading and in laying them, they are very liable to further casualties. The Author has observed many cast-iron sleepers broken for want of proper packing, and from settlement of the ballast in wet weather, or otherwise. It should likewise be remembered, that the broken sleepers have not the same value in India as old metal that they have in England, as there are not at present in India the same facilities for smelting and re-casting.

In conclusion, the Author would recommend that a fair trial on a new footing be made with the native wood sleepers;—that all woods now known, or hereafter found, to be good be used plain;—that proper care be taken in the selection, felling and seasoning of them;—that the sleepers be tarred in the seats of the chairs; and that they be laid in the driest ballast, which should be raised slightly in the middle and sloped off so as to direct the water under the rails. He would also recommend, that all woods which will not last plain, be creosoted, or otherwise prepared.

The main object of this Paper has been to give some facts relative to the resources of India, as regards timber for railway purposes, and to draw attention to what appears to have been passed over without sufficient consideration—the possibility of turning to account the native woods hitherto believed to be useless. At the same time, the general want of experience on these subjects, and the great importance of more knowledge regarding them, must be admitted. In India it is difficult for an Engineer to profit by another's experience. The distances are so great, and personal communication is so rare, that it is not easy to obtain accurate information beyond the immediate neighbourhood. Each individual has to struggle against the same difficulties, to try the same experiments, and to encounter the same failures. As has already been remarked, if those in whose power it lies would collect the experience of the agents of the different Railway Companies in India, and would then generally communicate the information so collected to the agents, a saving would be effected to Railway Companies in the cost of construction and of maintenance, and, possibly, by the discovery that native wood sleepers might be used with advantage, would secure for India all the good which must follow the use of so large a quantity of her own products.[1]

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[1] The following extract from 'The Times' confirms the statements in the foregoing paper:—

"*Calcutta*, *Jan.* 8, 1863.

"If I were asked what is at the present moment the most pressing of India's wants, I should say, the want of timber. It is as difficult to realise this fact in a country one-third of which is supposed to be covered with forests, as it was lately to believe that our Eastern Empire is so under-populated as to render the immigration of Chinese and others desirable. But the want of wood is more and more felt every day, and the country is scoured by contractors eager to supply railways and other public works. Take the one item of railway sleepers. India is a country where damp, dry-rot, and white ants consume the best sleeper in six years. For the past ten years all over the country we have been busy in laying down new lines, and all attempts to use iron or stone sleepers have proved unsatisfactory. We have still nearly 2,000 miles to complete, besides the numerous feeders and branches which are being constructed. Creosoting has been tried, but it is doubtful if that is of any advantage. At this moment the railway might be open to within 12 miles of Delhi right through from Calcutta, instead of only to Agra, if sleepers could be procured. And what will Government and the shareholders say to the cost of renewing the sleepers, which, on the Calcutta and Delhi line alone is estimated, at present prices, at £130,000 a year? Except in Burmah, where Lord Dalhousie strictly shut up the forests, so that now, under a good system of conservancy, they yield perennial supplies, we have cleared the forests away wherever we have gone. Indeed, the old rules for grants of waste land insisted on a certain extent of clearing every year under pain of forfeiture. The result is, that wood is not to be got in our own territories, unless in very inaccessible places, and timber from the north of Europe begins to figure largely in our imports. Not only so, but by clearing away trees, especially on the sloping ridges of hills, we have made the climate in some places rainless, and in others, because there is no belt of wood to catch and keep the periodical rain, the district has become barren, just as Palestine is, and from similar causes. With some degree of thoughtlessness, Lord Canning gave away to Sir Jung Bahadoor, of Nepaul, our finest forests, which he has closely shut up as a hunting ground; and in another case, after the late Viceroy had promised a district, containing our next best forests, to a Mussulman chief for loyalty in 1857, he had to submit to the humiliation of asking it back when he found that there was no other well-wooded tract in the North-Western Provinces."

[Mr. Burt

Mr. Burt said, he was not prepared to hear so favourable an account of the sleepers first sent out to India,—because they were of the triangular form, cut from blocks 9 inches square, and therefore having a sectional area of only 40 inches, and because the same care was not taken in the selection of the timber, nor was it so thoroughly impregnated with the coal-oil, as was now found to be necessary. From the commencement of the establishment of railways in India, in 1854, down to the present time, timber sleepers had been supplied from this country, and a large portion of them had passed through his hands. The sleepers latterly used were of the rectangular form, with a sectional area of 50 inches; the timber was of a superior quality, and great improvements had been made in the process of creosoting. The minimum quantity of creosote generally required to be absorbed was about 10 lbs. per cubic foot; but it was possible, with well-seasoned wood, to make it take up even more than that quantity. Formerly, in the winter time, creosoting operations were partially suspended, as it was found that, at a temperature below 40°, the creosote coagulated to such an extent as to render it almost impossible to force the preservative material into the timber. At present, by raising the temperature to 120°, and applying a pressure of 120 lbs., and maintaining both, so that all the time the timber was under pressure it was kept at a uniform temperature, the process was so effectually carried out that failure was nearly impossible. After an experience of twenty years, during which time he had sent about one million and a half of sleepers to India alone, besides having prepared many thousand loads of timber for other purposes, he could safely assert that the instances of failure had been rare and isolated. In those cases where decay had taken place, it had been found on inquiry to be due, either to the operation not having been properly performed, or to the timber having been cut and framed after being prepared. As a collateral proof that this mode of preserving timber was considered satisfactory, he mentioned that the process was now more extensively employed than at any former period, and that he had contracts in hand for the supply of nearly half a million sleepers.

The Author of the Paper recommended, that creosoting establishments should be formed in India; but he did not appear to be aware of the late Mr. Rendel having already tried that experiment upon an extensive scale, without success. A large apparatus was sent out, complete in every respect; but the heat of the climate rendered the process so dangerous for the workmen, and the cost of conveying the creosote from this country was so great, owing to the risk of fire, that the attempt was abandoned. The Author had estimated that sleepers might be creosoted in India at a cost of about one shilling each. Mr. Burt however calculated, that, supposing the oil to cost in this country from threepence to fourpence per gallon, and that one gallon was used for each cubic foot of timber, and taking into account the expense of transit in iron tanks, and the difficulty of carrying out the operation in India, the sleepers could not be properly prepared for less than three shillings and sixpence each.

A question had recently arisen, as to the possibility of supplying sleepers to India from Australia. An experienced agent had been sent out to collect timber suitable for shipbuilding and for railway sleepers; and a cargo of timber was despatched from Australia, but unfortunately both the ship and the cargo were lost on the passage. From the information he had obtained from various sources, Mr. Burt had arrived at the conclusion, that a supply of wood for sleepers could not be relied upon from that quarter of the world, at all events not as a profitable commercial speculation. There was great difficulty in getting freights from the western part of Australia to India; added to which the Jarra wood was so heavy, that the expense of inland transport would be a serious item. This wood weighed 64 lbs. per cubic foot, so that the weight of a sleeper would amount to 1 cwt. 3 qrs. 15 lbs., or nearly three-quarters of a hundredweight more than if of ordinary timber. It was also very hard, so that the conversion of it would be costly, and when used in a hot climate, it was liable to 'shakes' and to split. Other Australian woods which had been tried had not been found to answer so well as had been at first expected.

Mr. GEORGE BERKLEY said he had sent out creosoted sleepers to India; but, chiefly on account of the difficulty and the cost of conveyance to Bombay, preference was given to the process of kyanizing, as applied to the native jungle woods. It was the opinion of the late Mr. Robert Stephenson, that almost all the systems of saturating timber with essential oils, or with mineral salts, for the purpose of preserving it, would, if well done, be more or less efficient, and in that opinion Mr. Berkley entirely concurred. Teak was the best kind of native wood for sleepers, and its cost was about the same as that of creosoted timber sent from England. There were, however, many descriptions of native woods which were considerably less expensive. He was not at present prepared with any facts, as to the relative durability of native wood and of English creosoted sleepers; but on some future occasion, he hoped to be in a position to state the results of the comparative value of the different descriptions of sleepers used on the Great Indian Peninsula Railway.

Mr. JAMES WALKER, Managing Director of the Madras Railway, conceived that the Author was, from his position and experience, well qualified to give correct information on this important subject. It might, however, be broadly stated that the native woods of that part of India had generally proved unfit for the purposes of railway sleepers. The late Resident Engineer-in-chief of the line was engaged, at the time of his death, in preparing a Report upon the native woods. In the draft of that Report, Mr. Ross stated he had been gradually brought to the conclusion, that with the exception of Teak, Erool, and Vengay, none of the woods of that part of India were to be depended upon for sleepers. He believed most of the Engineers who had experience in India coincided with that opinion; and the result was, that the use of native woods had been in a great degree abandoned. Iron sleepers were now being resorted to, and he thought they would ultimately be used on all the Indian railways. With regard to creosoted sleepers, he agreed that wherever the essential oil penetrated, the preservation of the wood was complete; but the difficulty was to insure thorough penetration. If the heart of the timber was not completely saturated with the creosote, it decayed, leaving a hollow which would sooner, or later be crushed in. With respect to the Jarra timber of Australia, he might state that a trial of that wood was made on the Madras Railway, and as far as durability was concerned, it had proved satisfactory; but it was found, as had been stated, that it was very liable to shakes, and as in the case of Teak, the high price of the timber prohibited its use.

Mr. COCKBURN CURTIS, having been employed under the Department of Public Works of the Madras Presidency, prior to the establishment of Railways in India,—had had some opportunity of observing the effect of the climate upon the different kinds of woods in use in that Presidency, and hence could form some estimate, as to their probable duration when used as railway sleepers. The woods of the Madras Presidency were naturally divided into two broad classes,—those of a light spongy character, manifestly unfit for the purpose, and those of a heavier and denser kind. Of the denser, with the exception of Teak and one or two other woods of a similar oily character, he was unaware of any which could successfully stand the test of exposure; and even those woods required a free current of air, and the most careful periodical examination, to prevent the accumulation of moisture in the joints, or other parts of a structure where the wet might be liable to lodge. He also considered that it would be found very difficult to prepare the denser kinds of wood by any of the ordinary modes of injection, and that upon after-exposure to the moist heat of the rainy monsoon and the desiccating heat of the dry monsoon, it would be found that the outer part of the sleepers would crack, as they did in their natural state, and they would thus let the water into the centre, and more rapidly promote its decay. He therefore feared that the Author's praiseworthy exertions, to render the natural resources of the Madras Presidency available, and to afford increased employment to the natives, would be unattended by the success which they so decidedly merited.

It was probable that some of the woods found at Singapore might be suitable for railway sleepers. The Chinese, who were not bad judges of wood, were in the habit of exchanging the masts and spars which they brought in their vessels from China for others of Singapore woods.

Mr. SHEILDS stated, from his experience in the use of Australian woods, that it was the custom in that country to cut down the timber as it grew, to convert it into the required shape, and to use it without any kind of seasoning, or preparation. It was not to be supposed that timber, under such conditions, would, when exposed to the burning sun of India, endure for any long period. He believed that when properly seasoned, as all timber required to be, by the use of some simple means of preparation, such as immersion in water, or exposure, under cover from the sun, to a current of air, Australian timber would be found as durable as that of any other country: and he knew of none in any part of the world which was equal to it in strength, or tenacity. It approached inferior wrought iron in tensile strength, and possessed excellent properties, if it was subjected to fair treatment. He thought more might be done with Australian timber than had been the case hitherto, and he considered the use of it should not be abandoned without further trial.

Mr. COODE said, as reference had been made to the difficulty of impregnating with creosote the denser woods of India, he might state that eight, or nine years ago he had tried an experiment upon Saul wood. The result was that at the first trial only about 2 lbs. of oil per cubic foot were injected. The wood was then laid by, and from the evaporation which took place in the course of a fortnight, or three weeks, about half a pound in weight was lost. On a second trial this half pound was again injected. The process was frequently repeated with the same result; the piece recovering only what it had lost in weight subsequent to the last trial. The experiment, though on a small scale, was sufficient to corroborate what had been stated, as to the difficulty of impregnating the denser woods with any considerable quantity of creosote.

Mr. A. BRYCE remarked, that from his experience in the use of Indian jungle wood for sleepers, he believed the resources of the jungles, under a proper system of working and organisation, would be equal to supply all the demand that was likely to be made upon them. In the case of the Madras Railway, the sleepers were in the first instance supplied in small parcels by native contractors; but they were found to contain a great deal of sap wood, which decayed in the first, or second year. That was, however, entirely owing to the jungles not having been worked under proper direction and superintendence. If that were done he thought an immense quantity of fine timber, available for sleepers, if for no other purpose, could be delivered at any part of the Madras Presidency at a price of six shillings each sleeper, which was less than their cost, if they were sent out from England. As to the question of durability, he believed more extended experience in the use of the native woods was required, before a satisfactory opinion could be formed upon that point. He agreed with the Author, that the generality of the woods of India were of too dense a nature to be submitted to creosoting, and that they would with difficulty be rendered more durable by that process.

Mr. JENOURE remarked, that the deodara cedar, which could be procured in some parts of India, and which was stated on good authority to be very durable, when constantly exposed to the weather, as bridges constructed of it had lasted five hundred years, was omitted from the list of the native woods enumerated. He doubted the policy of any artificial application to young and green timber. It was acknowledged that young timber was the best for creosoting, but it was an established fact, that natural productions of all kinds used before their arrival at maturity were deficient in lasting qualities. He urged the importance of selecting timber of a proper quality and age, of felling it at the proper time, and of paying close attention to its due and gradual seasoning before it was used; and he believed, that much of the failure attributed to the native woods arose from neglect of these essential considerations. Numerous examples of the durability of timber, as prepared and used long before the days of creosoting, kyanizing, or any other patent process, were to be found in old English wooden houses which had stood for centuries.

Colonel SALE remarked, as the result of his experience in Bengal and the north-west provinces, that he believed there was no necessity to go beyond India to procure wood suitable for sleepers and for other railway purposes. As regarded Teak, Saul, and Soondry, if these woods were cut down in a ripe and sound condition, no artificial process was required for their preservation. The process of injection was beneficial when the timber was young, but when it had a good sound heart, it was not necessary, as it would be as durable in its natural state as the inferior woods when artificially prepared. In buildings, the wood was not so much exposed to the action of the elements as it was in the case of railway sleepers; but he had known Saul wood last for twenty-five years without requiring to be renewed.

Mr. CHARLES GREAVES said, upon the subject of the relative value of wood and iron in the construction of the groundwork of Indian railways, he could confirm the opinion as to the great inferiority of wood. It still remained a question, whether the creosoting process could be beneficially, or at all, applied to the hard-grained woods of India; but the majority of the woods of that country were so full of moisture in their growth, were of so perishable a nature from the effects of wet and dry rot, and wasted, shrunk, and diminished so much under exposure to sun and air, after the saturation they suffered in the wet monsoon, that a duration of three, or four years was the utmost that could be expected. There were a few descriptions of wood of an oily nature. Teak particularly partook of that character, and was unquestionably the finest wood of the country. Saul somewhat resembled it, but was harder and heavier; it was a very strong and serviceable wood, but would be expensive for sleepers. The wood universally used for building purposes in Calcutta was Saul, for all beams, cills, door-frames, rafters, &c.; whilst for ship-building Teak was as invariably employed; but masts were sometimes made of Poon wood, from Singapore and the Straits of Malacca. The way in which European woods were affected by the action of a tropical climate would surprise any one who had not witnessed it. The strongest English woods, when exposed, unpainted, first to wet and then to the heat of the sun, lost their coherence and strength; just as willow, or poplar did in this country. Saul timber, until it was very thoroughly dried, was heavier than water, and notwithstanding its hardness and strength, nearly resembling African oak, it was very liable to the attacks of white ants. For these reasons and for many others, which several years' residence in Bengal, in active practical work, had taught him, he was strongly in favour of the use of cast iron, as by far the cheapest material for any work intended to last twenty years. No doubt the jungle woods could be made to absorb creosote, and their durability would be to some extent increased, but the practice of the natives was sufficient evidence, that they were only of use for the most temporary purposes.

Mr. C. H. Gregory, V.P., was glad to hear the observations which had fallen from Colonel Sale, for if they had not been made, the Meeting might have lost sight of what he believed to be the fact, that it was the condition in which the native woods were used, added to the want of a proper selection of them, which had mainly led to their being condemned. The use of unsuitable native timber on some of the Indian railways was naturally explained by the large and sudden demand for sleepers. It had been his duty to investigate the character of the Ceylon woods, and their fitness for railway sleepers, and having obtained the best information he could, from the records of the Government Departments, and from other sources, he found that there were certain hard woods of

Ceylon, akin to those of India,—such as Satinwood, Millille, Ironwood, Jack, Gal-mendora, Ebony, and Paloo, which were extensively used for the public works in Ceylon, and which, in respect of durability, had given great satisfaction. In dealing with this question, all the woods of India ought not to be condemned, unless it could be satisfactorily shown, that the best woods which the country afforded had been selected, and had been used in a proper condition.

February 10, 1863.

JOHN HAWKSHAW, President,
in the Chair.

No. 1,053.—"Description of the Drainage of the Borough of Dundee."[1] By JOHN FULTON.

THE borough of Dundee, which is situated on the north bank of the estuary of the river Tay, contains a population of nearly one hundred thousand persons. Its police boundary includes an area of about 6 square miles, and the value of its assessed rental is not less than £218,000. Its docks cover an area of 30 acres, and the annual registered tonnage of shipping entering and leaving the port is 288,557 tons.

Previous to the year 1851, the town of Dundee was in a very defective condition, in a sanitary point of view. With the exception of three, or four streets, it was wholly undrained, and the sewage flowed on the surface of the streets and 'closes,' or it was discharged into cesspools, having no other outlets than the surface channels. There existed few places of convenience, and the scavenging was imperfectly performed. The consequences were a prevailing high ratio of deaths from typhus fever, and several outbreaks of cholera, not to speak of numerous minor evils, all traceable to the same cause.

In the year 1851, by the vote of a majority of the ratepayers, the town was brought under the powers of the General Police Act for Scotland, which somewhat resembles in its provisions the Health of Towns' Act for England; but although other sanitary measures were then adopted, such as improved paving, cleansing, &c., owing to a defect in the drainage clauses of the Act, which had to be amended by Parliament, the sewerage of the town was not commenced until the year 1856. It has, however, progressed steadily, year by year, since that date, and, with the exception of a few minor details, it is now completed. The work has been five years in progress, and has cost the sum of £52,000, which is only £2,000 in excess of the estimated amount.

The site occupied by the town is slightly embayed. The substratum on which it rests is for the most part composed of trap rock; but at the east end of the borough, this merges into sandstone. These rocks are generally found near to the surface, and in some places they project above it; this occurs more particularly in the centre of the town, where at a not remote period, the fort, or castle of the town, occupied one of these eminences near the river, and about 50 feet above its level. Surrounding the castle rock for some distance, and extending at a right angle from the river about 1,000 yards, the substrata are clay, silt, and water-rolled gravel. The clay contains many indications, such as branches, leaves. nuts of hazel, &c., of having been deposited in water; and the fact of this portion of the surface being very flat, and only slightly elevated above the sea level, tends to prove that it was at one period an inlet of the river. The ground extending inward from this basin, or level tract, rises rapidly, the gradient of several streets being 1 in 7. The highest portion of the town has an elevation of 300 feet above the mean tide level; but the 'law,' or hill immediately behind the town, rises at a still steeper slope to an elevation of 570 feet, and forms a prominent object in the landscape.

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[1] The discussion upon this and the following Papers occupied portions of two evenings, but an abstract of the whole is given consecutively.

The town was at one period surrounded by a wall, and that portion is closely built, with narrow and crooked streets. The houses are crowded into courts and passages, and many of the latter, not more than 6 feet in width, have houses on each side, three, or four stories high. In both the old and newer portions of the town, the houses are almost without exception built of sandstone, the walls being of great thickness and weight. The public works, such as mills and factories, are also stone erections; the chimney stalks alone being built of brick. These particulars are given merely to illustrate the nature and difficulty of the work under consideration.

It has been stated, that three, or four sewers existed, previous to the commencement of the works here described. One of these, which was constructed by the Harbour Trustees to intercept the drainage of the town and to prevent it from entering the docks, or the tidal basins, extends the whole length of the harbour, about 1,600 yards, and runs for the greater part of its length nearly parallel to the river. It has a fall of 1 in 400, and its average depth is 15 feet. Its discharging end is 21 feet below the surface level of the quay, or 8 feet below the level of mean tide. It is built of substantial rubble masonry, and is of rectangular form, its dimensions being 7 feet in height, by 3 feet 9 inches in width. This sewer forms the chief outlet for the drainage of the town, including the sewage and flood waters. The entire surface drained by it has an area of upwards of 1,000 acres. The sewage discharged by it, in dry weather, measures 2 feet in depth, and during storms 6 feet. The velocity in the former case is 65 feet per minute, and in the latter 116 feet per minute. There are two other outlets, one of which drains a suburb containing a population of about 4,000 persons; the other is required for flushing purposes, and acts as a relieving sewer during floods. They measure respectively 3 feet 6 inches by 2 feet 3 inches, and 4 feet 6 inches by 3 feet, and, in section, are of the egg form.

A line of railway extends along the river margin for several miles above and below the town, which effectually deprives the population of any use of the stream for bathing. But one redeeming feature of this evil is, that it permits the sewage to be discharged at once into deep water, and thus prevents a nuisance.

In designing the drainage under consideration, one primary object kept in view was the application of the sewage to some useful purpose. Accordingly, the whole drainage, so far as was practicable, has been carried to one point, the outlet first referred to. It is proposed to form a well near the junction of this outlet with the river, and from this by steam power to lift the sewage and force it through cast-iron pipes 12 inches in diameter, to the sands of Barry, a district on the shore of the estuary, about 7 miles below Dundee, and there to apply it in the liquid form as at Edinburgh. The Dundee and Arbroath Railway runs in almost a straight and level line between this outlet sewer, and the tract of land in question, the improveable portion of which is not less than 2,000 acres; and as it is of a level character, the formation of embankments through it, for conducting the sewage, would not be expensive. This land is on the estate of Panmure, the property of the Earl of Dalhousie, and it would be for his interest to carry out this scheme to completion, as the return from it could not fail to yield a handsome profit, the land at present being comparatively valueless. The sewage of the town is in the meantime allowed to flow directly into the river, and is thus lost. This is, however, the utmost extent of the evil, as it causes no nuisance, being speedily dissipated in the stream, which is upwards of a mile in width opposite the town; and the point of discharge of the chief outlet sewer is more than 400 yards from any dwelling.

The drainage has been carried out by a combination of brick sewers and salt-glazed, fireclay, socket-pipes, of dimensions suitable for the discharge of the sewage and the flood waters together. The brick sewers, which are all of the egg-form, are confined to the leading thoroughfares: their dimensions are respectively, 3 feet by 1 foot 10 inches, 3 feet 6 inches by 2 feet 3 inches, 4 feet by 2 feet 9 inches, and 4 feet 6 inches by 3 feet. The diameters of the pipe sewers are, 9 inches, 12 inches, 15 inches, and 18 inches. The leading thoroughfares converge to a point in the centre of the town, and, as already explained, this has been taken advantage of in regard to the main outlet. The streets drained by tubular sewers are chiefly those at right angles with the river, which are the steepest, and therefore the most suitable for tubular drains. The joints of all the tubular sewers have been made with clay.

The average depth of the sewers is 12 feet, which was considered necessary in order to secure proper drainage of the cellars. The surface levels being very irregular in many places, the depths of the cuttings consequently varied, the smallest depth (which was in trap rock) being 7 feet and the greatest 21 feet. The deepest cutting in trap rock—19 feet—occurred in the centre of the town, across the base of the Castle Rock.

The total amount of rock excavated was 24,000 cubic yards. The greater portion of this had to be removed by means of gunpowder; and although in most cases the work was done in narrow and crowded lanes and streets, no serious injury occurred to persons, or property. It was even found necessary, in some cases, to use gunpowder inside dwelling-houses, in the formation of branch drains, but by proper precautions, such as the selection of cautious and intelligent workmen, using only small quantities of gunpowder to each shot, and carefully covering and loading the rock, casualties were prevented. The contractors were paid for excavating this rock by measurement as it occurred, and as an extra, per schedule price. Running sand occurred in many places, and occasioned much trouble and expense. In one lane not more than 9 feet wide, with ponderous buildings on each side, having their foundations near the surface, a bed of this sand was found at the depth of 9 feet. The sewer was in this case of large dimensions, and 12 feet in depth, but by shoring the buildings, and using cofferdams, all injury was prevented. It was, however, found requisite in this and many other instances to leave nearly the whole of the timber lining in the trench. The sums paid to the contractors on this account have consequently been very heavy, the total amount being £3,600; but this includes the timber used for supporting gas and water pipes. In several streets, where the strata were sufficiently solid, tunnelling was resorted to; but this was found unsatisfactory, and was soon given up, because of the uncertainty of securing thorough consolidation of the spaces having to be filled up over the arches, or pipes.

The numerous gas and water pipes were a source of great annoyance. In the older portions of the town, more particularly, these were found to occupy the centres of the lanes and streets, which, as already stated, are for the most part narrow and crooked. There being, moreover, three Companies having distinct mains and branches, and in some cases two sets of pipes, the difficulty may be conceived, and indeed the danger of constructing any kind of drain under such circumstances. It was found absolutely necessary in some instances to remove several of the pipes for a time, or permanently, and the cost of this, as well as of the unavoidable breakage of pipes and loss of gas, has been very considerable—the total amount claimed by the Companies being upwards of £1,100.

The contractors, being held liable for all damages, have paid the greater portion of this amount; the Commissioners of Police having only borne the expense of the alterations of the mains. Ample allowance was, however, made to the contractors for timber supports to these pipes. Many of the pipes were found to be in a frail condition, and their contents escaping into the houses caused considerable injury to persons and property.

The leading, or intercepting sewers have been made from 12 inches to 18 inches deeper than the lateral and branch drains, with the view of preventing the ends of the latter from silting. This has been found to be a wise precaution, as in those sewers possessing little fall, sand speedily accumulates. The quantity of sand, and the time in which it is deposited, are, however, materially influenced by the quantity of water passing through the sewers, and up to a certain point it may be, and is, entirely prevented by a proper system of flushing. This point commences with a fall of 1 in 600, the earthy and more soluble matters being then carried off by the ordinary rain-fall and sewage; but a deposit of coarse sand is left behind in all sewers having no greater fall than this. It is not apprehended that much annoyance will arise from this source, as none of the sewers have a fall of less than 1 in 700.

Manholes with brick walls 9 inches thick have been carried up to the street level, from both the brick and the pipe sewers. They have been placed at the junctions of the leading and lateral sewers, and at intervals of 40 yards along each sewer. They are provided with covers of cast iron, having frames 8 inches deep to suit the paving stones of the streets, and grooved lids hung on wrought-iron axles. Projecting bricks are built on opposite sides of the manholes to serve as ladders, and they answer this purpose very well. In the pipe sewers the manholes are extended on each side, to give room to the workmen when cleansing the sewers. The use of these manholes will be explained in describing the sewer-cleansing apparatus.

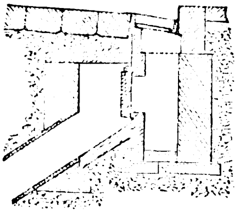
The junctions for the house drains and gullies were built into the sewers, as the work proceeded. They consist merely of the ordinary socket pipes, with bevelled ends to suit the form of the sewer. A flat stone is placed on the exterior end of each pipe, until it is required for use, to prevent earth, or sand, from falling through into the sewer. In the case of tubular mains, socket junctions, having an acute angle, were placed at intervals, or where they were required for branches, or gullies, and their positions were defined by marks made on the walls of premises at right angles from them; and in addition, a register of all branch junctions is retained in the surveyor's office, describing their depths as well as positions, and the nature of the strata to be excavated.

The brick sewers are all provided with invert blocks of glazed fireclay, 2 feet 6 inches in length, and have walls and arches 9 inches thick, the latter being turned with two rings of half brick. Where the sub-strata were of a wet, or yielding nature, it was found necessary to prepare a bed of concrete for the reception of the invert blocks; and where the sewers were subject to the influx of the tide, the side walls were built in Roman cement. The form of the brick sewers is shown in Fig. 2, page 10.

The gully drains are placed at intervals of from 30 yards to 60 yards apart, the steepest streets having them closest together. They are for the most part made with faucet pipes, 6 inches in diameter; the streets in the lower, or level portion of the town having pipes 9 inches in diameter.

The gases of the sewers are prevented from escaping through the gullies, by valves made of stone, hung with copper links, on one side of a small cesspool (Fig. 1). The bottoms of the cesspools are 10 inches below the lower sides of the valves; by this means all heavy matters, such as sand and stones, are prevented from entering the sewers. These gully drains are meant for the reception of rain water only; the cesspools being cleansed weekly by the scavengers, during the prevalence of wet weather. This form of gully has been found very suitable in Dundee. A few water traps were at one time in use, but owing to the constant flow of hot water through the sewers, from the spinning mills and other works, they soon dried up and became useless. The valves on the contrary meet all contingencies. They freely pass the flood waters, and the cesspools retain all the heavier particles of road detritus.

Fig. 1.



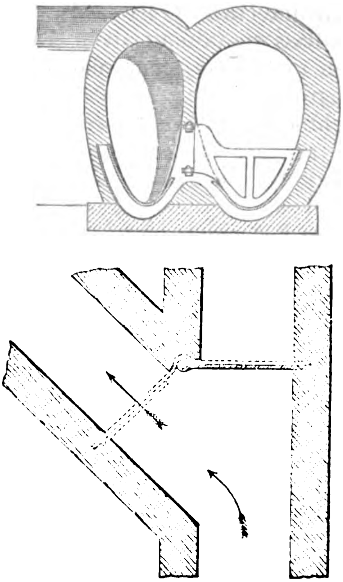
Gully Drain.

The branch drains, where they are connected with the sinks and water-closets in houses, have no other traps than those of the syphons which are placed in immediate contact with the sinks or water-closets. These are found to answer every purpose, and anything additional would be superfluous. Many persons are under the impression that more than one trap on a drain is requisite, a cesspool being considered by them indispensable. It will be found by experience, that cesspools, on drains of this kind, create rather than remove a nuisance, and that there is in reality no nuisance to remove, as one trap only, if properly constructed and applied, is perfectly sufficient to prevent the escape of all emanations from sewers. This trap ought always to be placed as near the sink, water-closet, or grating used for the reception of soil water as possible, and in such a position as to be easily accessible for cleansing, or for repair. Another reason against the use of cesspools, except as now recommended, is that they retard the flow of the sewage in the drain, and cause it to become choked. The branch drains have in all cases been made with glazed stoneware, or fireclay socket pipes, from 4 inches to 12 inches in diameter. In back courts and passages, and for the use of the working classes, stone basins, with gratings of cast iron, containing water-traps, have been provided, and where many tenants use one basin, an additional grate is placed over it, to prevent its misuse. It was found in several instances, that the branch drains were choked by the tenants lifting the gratings, and throwing into the basins ashes, fish offal, and other unsuitable matters; but this has been entirely prevented by an additional grate of wrought iron, 12 inches square. The total number of house drains made, up to December, 1861, is one thousand eight hundred: many of these branches drain passages and courts serving a numerous population.

The town is supplied with water on the principle of gravitation, by a Company established by Act of Parliament; and this Company has received, as one of the effects of the drainage operations, a considerable addition to its income, in the form of water rents. The owners of property, having in many places no means of getting rid of waste water, had neglected to provide their tenants with any water supply, and they were consequently under the necessity of purchasing it in small quantities, as sold at stated intervals by the servants of the Company from their hydrants, or of begging from their more fortunate neighbours, or what was too frequent, they were compelled to use water taken from the street channels and open water courses, for washing their clothes, for which it was quite unsuited. This state of matters no longer exists, as in nearly every case where a branch drain has been constructed, a branch water pipe has been laid, and the requisite tap been provided.

The water supply being in the hands of a Company, it was needless to think of flushing the sewers from this source, as the expense would have been too great. This led to the adoption of the only other mode of flushing available, which was to intercept the sewage at any suitable point, by means of a cast iron gate, and to turn it into any sewer, or special series of sewers. The various levels have been taken advantage of for this purpose, and by means of a series of gates of this description placed at the junction of the sewers, Fig. 2, and immediately under manholes, giving ready access to them, the greater portion of the sewers have been rendered self-cleansing. As already explained, it is found, that in sewers having little fall, say 1 in 600, there is a tendency to the accumulation of sand, and in pipe drains with even greater fall than this, where the ordinary house drainage only exists, sand also accumulates. This occasioned the invention of a cleansing apparatus to be hereafter described. The flushing gates are only 15 inches deep, and they answer the purpose of overflow weirs, preventing the sewers, during floods, from being subjected to pressure, by allowing the surplus contents to flow into subsidiary outlets, and thus equalizing the flow of water. It has been proposed by some Engineers to provide two separate lines of sewers, the one for rain water and the other for soil water; but it is suggested, that the above particulars prove the impolicy of such a system, as without rain water, unless with very steep gradients, the sewers would soon silt up. This is only one objection out of many that will readily occur, such as the great additional cost, the difficulty of providing two sewers in narrow lanes, and of gaining access to them, &c. It has also been proposed to use tubular drains under pressure; but this is believed to be a fallacy, as stoneware, or fireclay tubes will only bear a limited amount of pressure, and the Roman cement joints would bear still less. Again, if drains of any kind are to be put under pressure, how can their contents be prevented from rising through the branches into the cellars, or other places drained into them, and how are those cellars to be drained? These questions must be satisfactorily answered, before

Fig. 2.



Plan and Section of a Sewer at a Junction.

any attempt is made to apply a general system of 'head' pressure to sewerage.

The whole of the sewers within the borough are provided with manholes, or entrances carried up perpendicularly from the arch of each sewer, and at intervals of 40 yards. When a sewer is to be cleansed, a windlass containing about 45 yards of iron chain is placed over each of two adjacent manholes; a series of rods each 4 feet in length extending to 40 yards, and composed of iron tubes (for lightness), with screwed ends fitting into each other, is then put together at the bottom of the manhole, and is pushed by hand to the next manhole, where the rods are again unscrewed as they are drawn through. The chain being attached to the last rod is by this means carried along the sewer, and affixed to the cleansing tool in connection with the other chain and windlass. Horizontal and vertical bars of iron with clamping screwed-slides to suit any size of sewer are then fixed, the vertical bars having iron pulleys on their lower ends with hinged openings through which the chain is passed. As the matter to be removed from the sewer usually consists of hard sand, a tool is first attached to the hooks of the chain, in order to plough, or break it up. When this has been sufficiently done, a scraper is next drawn through. This scraper is formed of strong plate iron, and is furnished with small wheels, on moveable axles, on its lateral and lower edges. It has usually to be drawn backward and forward several times before the required cleansing is complete. The stuff removed is taken to the surface in buckets by the windlass, or by hand-ropes.

The cleansing of tubular sewers is somewhat different. In this case the manholes are enlarged underneath, to give room to the workman, and also to admit of the pulley bars being properly secured. The jointed rods require to be forced through the sewer, by the aid of the windlass and chain and a strong pair of pincers; and they are removed from the next manhole in a similar manner, or are carried farther into the sewer, as may be requisite. The scraper for pipe sewers does not require wheels; but to prevent its adhering to the end joints of the pipes, it is provided with fenders composed of rods of wrought iron passing over its edge, and terminating in a ring at each end.

The cost of cleansing sewers by this mode is on an average:—For tubular sewers, one penny, and for brick sewers, two pence per lineal yard.

No sewer has hitherto required to be cleansed oftener than once in twelve months; and those sewers requiring this service are chiefly such as have not, from their shortness, a sufficient flow of water to keep them clear of silt.

Under-ground cellars near the level of high tide, or the water-run of the public sewers, and having branch drains into the latter, have in all cases been provided with self-acting flap valves of polished stone, similar to those used in the gully drains. These valves, when properly constructed and applied, are excellent safeguards against the flooding of cellars by storms, or by high tides. The stones used in their construction have a fine grain, and this, with an overlap of 2 inches on the opening, properly polished and adjusted, resists a considerable head pressure, and remains perfectly water-tight. The brickwork surrounding the valves (which are placed at the entrances of the drains) is in all cases built in Roman cement. These valves are only meant for occasional use, as if they were constantly closed by head pressure, the drains on which they are placed would be of no service.

The ventilation of sewers is a subject which has been much discussed, and apparently to little purpose. But as this Paper is merely meant to convey a description of a work actually accomplished, and not an essay on what might be done, it will only be necessary to state, that no ventilation whatever has been applied to the sewers in Dundee, and farther, that none is contemplated. No complaints have been made of bad smells issuing from the drains, nor are they likely to be made, as owing to their form of construction, the smallness of the dimensions, and the mode of flushing adopted, there cannot be any generation of gases from putrid matters retained in the drains, as all such matters are carried rapidly through them to the river, and thence to the sea. It is not denied that gases do to some extent exist in the sewers; for it is known that, irrespective of any other source, the mains and branches of the gas companies contribute their quota by their ordinary leakage, and the sewage must exhale noxious vapours in its passage through them. But the gases are not present in such volume as to overcome the ordinary traps, and they are carried off frequently by the flood waters. The only deposit habitually left in any of the sewers, or drains, is sand. This, on being taken up, emits no perceptible odour, and when closely examined, has all the appearance of ordinary river sand. It is only where sewers are badly constructed, as regards their form and water-run, that putrid matters are retained in them to poison the surrounding atmosphere, and to bring disgrace on the very name of drainage. No sewer under 10 feet in perpendicular dimensions ought to have an invert greater than 9 inches radius, and 6 inches is quite large enough for the radius of the invert of any ordinary sewer. When the sewage is confined to such a small compass as this, its scouring power is very great, and if care be taken to have the invert block laid in a straight line, with such fall as may be available, it will be found that, although the fall be slight, little silting will take place, and that it will consist of sand only. No ventilation is, therefore, requisite with well-constructed sewers. It is only where the scouring effect of the sewage is lost, by constructing sewers with flat bottoms, that such is needed.

The proportion of brick sewers constructed, to that of tubular sewers, is as one to two, the total length of the former being 10 miles, and of the latter 20 miles; and their cost is nearly as one to three, the average of the former being thirty-three shillings, and of the latter thirteen shillings, per lineal yard.

There being an abundant supply of excellent sandstone in the immediate vicinity of Dundee, it was at one time contemplated to build the larger sewers of this material; but on calculations being made, it was found that, unless with a very coarse description of rubble-work, the cost would be greater than that of brick-work, and that the work could be much more expeditiously carried out with the latter than the former; also, that the streets being narrow, they would not well admit of wide trenches to receive the thick walls required for masonry.

The drainage of the town having been so recently completed, sufficient time has not yet elapsed to judge of its effects on the health of the population; but it may be stated that, so far as can be ascertained, a decided decrease in the rate of mortality, as compared with former years, has taken place. One beneficial result of the work, however, is apparent; this is a general tendency of the people to more cleanly habits than formerly prevailed. Drunkenness and crime have diminished to a considerable extent; but this may be owing partly to other causes, which need not be mentioned here.

The Paper is illustrated by three drawings, from which the woodcuts, Figs. 1 and 2, are taken.

No. 1,064.—"Description of the Sewerage and Drainage Works, of Newport, Monmouthshire."[1] By ALFRED WILLIAMS, Assoc. Inst. C.E., F.G.S.

THE borough of Newport, Monmouthshire, which now has three thousand six hundred and ninety-five houses, and a population of 23,248 persons, extends over an area of 950 acres. It is situated on the River Usk, which discharges itself into the Bristol Channel about 3¼ miles below the southern extremity of the borough. A portion of the old town is built on the hill of Saint Woollos, crowned by the parish church, the base of which is 174 feet above high water. This hill is of the old red sandstone formation, but a very large proportion of the borough is on the flat alluvial deposit through which the river channel passes, the natural surface being about the level of high water of ordinary spring tides. The portion of this surface occupied by houses has been raised artificially with ballast, &c., the largest owners of building land,—the Tredegar Wharf Company (under the liberal management of Mr. Samuel Homfray,) —having persevered in carrying this out. Many of the cellars of the town are several feet below the level of high water at spring tides.

Newport being one of the principal shipping ports of a large and wealthy mineral district, is intersected in all directions by passenger and mineral railways, which cross the streets on the level. Within the borough there are about 5 miles of railways belonging to Public Companies, exclusive of innumerable branches to wharves, &c. The Monmouthshire Canal runs through the town for about 1¼ mile to the dock, which occupies an area of 12 acres, with an entrance lock 220 feet long by 61 feet in width. The principal part of the trade, however, is carried on at the river, where the wharves extend for upwards of 2 miles along the western, or right bank. The river, at the upper part of the town, is 450 feet wide at high water spring tides, and has a sectional area of about 12,000 feet; at the lower part of the town it is 900 feet wide, with a sectional area of about 26,500 feet. The rise of the tide in the river, at ordinary springs, is about 35 feet, and at extraordinary springs about 40 feet, and occupies only five hours, the current being necessarily very rapid. High water of extraordinary spring tides is 1 foot, and of ordinary springs 6 feet, below the coping of the dock, at the entrance lock. High-water of ordinary neap tides is 17 feet below the same coping.

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[1] The discussion upon this and the preceding Paper occupied portions of two evenings, but an abstract of the whole is given consecutively.

The town is efficiently supplied with water by a Company, the works for which were executed in 1847 and 1848, under the direction of Mr. James Simpson, Past-President of the Institution. All the water, excepting that for the very high part of the town, is supplied by gravitation.

Before the construction of the Sewers, which form the subject of this Paper, several miles of sewers and drains had at different times, during a long series of years, been constructed by Local Commissioners, landowners and others, on the western side, or right bank of the river, where nearly all the town stands. These for the most part were of rude design and rough material; many of them were small and square, and others were merely a rough stone arch over a ditch, without any invert. In many cases they were built to preserve the old watercourses and field ditches, without regard to the intended street lines, or to the buildings subsequently to be erected over them; consequently they often passed obliquely under houses and gardens. Some of the old sewers were, however, found to be substantially constructed, and with suitable falls, although they had not been laid out on any general system of levels. The later works were egg-shaped brick sewers, constructed where most urgently required, under the direction of the Author, in some cases with the sanction of the General Board of Health, and all arranged with a view to more extensive works. Many of the houses over, or near the old sewers, drained into them, but in the larger portion of the town cesspools were necessarily used. These old sewers, which varied in height from 1 foot to 4½ feet, discharged also a great portion of the land and surface water, the remainder running direct into the river, canal, dock, &c. There were nine open outlets into the river, varying in level from 5·4 feet to 12·9 feet below high water of ordinary spring tides; and the tide flowed up the sewers, and sometimes flooded the cellars and basements.

In 1856, the Author was instructed by the Local Board of Health to prepare "An efficient plan for the drainage of the borough, with estimate of cost of same, using, where possible, existing drains and outlets, with a view to a sound practical and economical system." In accordance with these instructions a carefully considered scheme was prepared, which received the sanction of the General Board of Health, and (with the exception of the cleansing and repairs of old sewers) was executed. The Plan of Newport which accompanies this communication, taken from that submitted for approval to the General Board of Health, shows generally the direction, &c. of the existing and proposed sewers.

The design was so arranged:—1°. That the outlets were to be reduced from nine to four, by intercepting sewers, (necessary for the drainage of the districts through which they pass); power being retained to use the abandoned outlets, without additional works, should circumstances require it. 2°. That the sewage of two-thirds of the town might be brought to the lowest outlet down the river, near the extremity of the borough; and by a further expenditure, if events should justify it, the greater portion of the remaining third might be brought to the same outlet. This was a new one, selected at a suitable point for the distribution of the sewage matter in a liquid form, or for its conversion into solid manure. 3°. That the gradients were generally favourable, considering the level of the great portion of the district, the flattest inclination of any new sewer being 1 in 488 near the lowest outlet, and nearly half the entire length of new sewers being steeper than 1 in 100. 4°. That no cost would be incurred in works, or for water for flushing; the plan being laid out so as to take advantage, for cleansing purposes, when required, of the land-water and the waste-water from the canal, and from ponds, feeders, &c. in the town, and water being also obtainable, on an emergency, from the waterworks, at any point.

In an aqueduct for supplying the dock with water from the Ebbw, constructed shortly before the new sewers, by arrangement with the Dock Company's Engineer, iron inverts, with openings, were inserted at two points over the sewers, so that water might be obtained for cleansing them: other provisions were also made in different parts of the town. For a considerable portion of the sewage, a choice of two, or three outlets is provided, which may be useful in case of cleansing, &c.; the only work necessary for altering the course of the water, or the sewage, being the use of a few moveable doors, or gates.

In a Report to the Local Board before the execution of the works, further details are given, but generally they are only of local interest.[1]

The general plan comprised about 7 miles of new brick sewers, varying in height from 14 inches to 4 feet 6 inches,—all above 14 inches being egg-shaped and narrow at the invert—with outlet works; a sufficient number of entrances with ventilating shafts; and street gullies; the contract for which was let to Mr. John Phillips, and by him successfully executed, under the direction of the Author. The plan also included the cleansing and repairing of some of the old sewers which were to be retained, and a considerable extent of new sewers, which the Author was instructed to make for the owners of land not yet built on.

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[1] A printed copy of this Report is appended to the Paper.

As regards the objection, which will no doubt suggest itself, to the course determined on by the Local Board of Health, (but to a considerable extent modified by the Author,) of using numerous outlets into the river within the borough, it must be observed, that the case of Newport is an exceptional one; the size of the river and the extraordinary rise of tide rendering the amount of sewage matter discharged into it comparatively insignificant. If, however, any present, or future discovery should prove sewer water commercially valuable at Newport, the objection will be still further weakened.

Of the four outlets necessary to the present system, two are old outlets, where a large quantity of land-water is discharged: for the remaining outlets, two points were selected which were suitable for the utilisation of the sewage, (if that should be found profitable,) and not near any houses; where the sewage water would have a short and steep run into the stream at low water; and where only short lengths of pipes would be required, should they be found necessary. The levels of the cills of the new outlets are 9·8 feet and 12·6 feet, and of the old outlets 8·8 feet and 12·6 feet, respectively, below high water of ordinary spring tides. When the outlets are closed, the sewers have for a time to act as reservoirs; but no practical inconvenience is found to arise from this, as means of ventilation are provided. The outlet valves were made by Messrs. Burton, Sons and Waller, of Southwark. The valve is formed by an iron disc, suspended loosely by chains, but when the tide rises it fits closely against a raised and planed surface on the iron work which is fixed in the masonry of the wall, the opening in most cases being smaller than the sewer. These valves are found to answer well; and although at extraordinary spring tides, there is a rise of about 17 feet above the cills of two of the outlets, and 6 feet above some of the lowest floors and cellars, no inconvenience is complained of, and the houses and cellars remain dry.

The sizes of the sewers were arranged to suit the quantity of sewage and water to be carried through them, as well as the rates of inclination, and other circumstances of the locality; regard being had to the advantage of making them sufficiently large for a man to pass through, where it could be done without an unjustifiable outlay.

In approving the design, the General Board of Health called attention to the successful working of stoneware pipes for sewers at "Salisbury, Sherborne, Southampton, Gloucester, Woolwich, Manchester, Carlisle, Rugby, and many other towns;" but the

Author considered it unadvisable to use them as main sewers in Newport, having regard to all the circumstances of the town, the existing works, the relative cost of brickwork and pipes, the quantity of debris washed from the roads into the sewers, as well as the difficulty of preventing improper interference after their construction, &c. In Newport all the roads are macadamized, the extent of private streets not repaired, or cleansed by the authorities, being considerable; and where the clearing of gully cesses is neglected, crushed stone and other matters pass into the sewers. The sewers have often been broken into, without the knowledge, or consent of the Local Board of Health, and if the labourers employed to do such work were to break a pipe, the probability is that the trench would be filled, and nothing would be said about the matter, until its effects became apparent on the house drainage of the neighbourhood. The danger of such an occurrence as this would be much increased, if the system of 'back drainage' (where pipe sewers are carried for considerable distances through private courts, gardens, &c.) were adopted. The cost of brick sewers, as compared with pipes, in Newport, may be thus stated. Brick sewers 14 inches diameter, and 4½ inches thick, and 10 feet deep, under the Newport contract, with radiating bricks specially made, and a junction pipe inserted for every house, cost complete 7*s.* 7*d.* per lineal yard. This is about the same as a pipe 12 inches diameter, well laid, with junctions, would cost. Sewers 2 feet 6 inches by 1 foot 10 inches of brickwork 4½ inches thick, similarly constructed, with junction pipes, and large enough for a man to pass through, at the same depth, cost 11*s.* per lineal yard. Excepting for small sewers under 12 inches in diameter, brickwork is, in Newport and in many other localities, cheaper, as well as more permanent, than pipes. The Author has found, in practice, great advantages in dealing with sewers constructed large enough for a man to pass through, if necessary; and although from time to time he has carefully weighed the advantages and disadvantages of pipes, he has most frequently constructed and recommended brick sewers, not less than 2½ feet high, for all important lines, excepting where the fall is very great. He has generally confined the use of pipes to house drainage, for which they are admirably adapted, to short branch sewers on steep inclinations, and to conduits for fresh water. In the district of the Christchurch Local Board of Health, which was drained by the Author, several hundred yards of pipes were laid parallel to one of the brick sewers, to convey fresh water for the use of a few houses.

The subjoined Table will, with Plate 4, show generally the sizes, thickness, and cost of the Newport Sewers, all excepting the first being egg-shaped:—

No. of Figure.	Internal Dimensions.				Thickness of Brickwork.	Quantity of Brickwork per Lineal Yard.	Average Depth of Cutting.	Cost per Lineal Yard, including Junctions.	
	Height.		Width.						
	Ft.	In.	Ft.	In.	Inches.	Cubic Ft.	Feet.	s.	d.
1	0	14	Circular		4½	5½	10	7	7
2	2	6	1	10	4½	9	10	10	11½
3	2	6	1	10	6	12⅓	10	13	10
4	3	0	2	2	4½ in. with 9 in. inverts	14 1/16	10	15	0
5	3	0	2	2	All 6 in.	14⅓	10	15	6
6	3	0	2	2	6 in. with 9 in. inverts	17	10	17	2
7	3	0	2	2	All 9 in.	23⅓	10	22	0
8	4	6	3	0	9 in. excepting crown 6 in.	27 1/16	12½	28	1
9	4	6	3	0	9	32 1/16	13⅓	31	5
10	4	6	3	6	9	33⅓	15½	35	0

The prices of the sewers up to, and including, 3 feet by 2 feet 2 inches are given for an average depth of 10 feet, for the purpose of easy comparison, though many of them were laid deeper. The depths of the sewers 4 feet 6 inches in height are the average of excavations actually made, the greatest depth being about 20 feet. The cost of the brickwork in mortar was 18*s.* per cubic yard for 9-inch work, 18*s.* 6¾*d.* for 6-inch work, and 19*s.* 1½*d.* for 4½-inch work; the earthwork cost about 1*s.* 4*d.* per cubic yard. A copy of the quantities and of the form of tender, which the Author arranged carefully, and found very useful in preventing trouble and disputes in the settlement of the contract accounts, is appended to the communication.

The brickwork was generally laid in mortar, composed of blue lias lime and clean sharp sand, in the proportion of 1 of lime to 1½ or 2 of sand, well mixed with water in a mill, and used fresh. The external surface of the crown of the sewers was coated with mortar about half an inch thick. Cement was used in some places for the brickwork and concrete for the foundations.

Before selecting the bricks for the work, a close, and in some cases a chemical, examination of the bricks obtainable was made; and it was ultimately arranged to procure machine-made bricks from the works of Mr. Tuckett, of Shirehampton, near the mouth of the River Avon, below Bristol, the samples of these having stood well the examination and tests of analytical chemists. They are made by machinery, (the clay having been previously passed through a pug mill,) some by steam and others by hand power; and they have a small longitudinal hollow, which reduces the thickness of the clay, and without materially weakening the brick, causes it to become more dense and be more easily burnt. For the 6-inch brickwork, radiating bricks 12 inches long 6 inches deep and 3½ inches thick, on an average, including the hollow, were burnt without difficulty; and were found to effect a large saving in many of the sewers, where otherwise two rings of 4½-inch work would have been used. The bricks for the 6-inch and 4½-inch rings were all made to radiate, to suit the invert, sidewalls, and crown of the several sized sewers; and in order to distinguish readily the different radii of the bricks, as well as to afford a key for the mortar, grooves varying in shape and number were made in the sides of the bricks, to indicate the radii for which they were intended. The inner and outer surfaces of the bricks were curved, to suit the respective radii, so that, when well put together, a very accurate sewer was formed. Some bricks of a similar character were made, for the side walls of the sewers, at Mr. Henry James's Court-y-bella Brick and Tile Works, Newport.

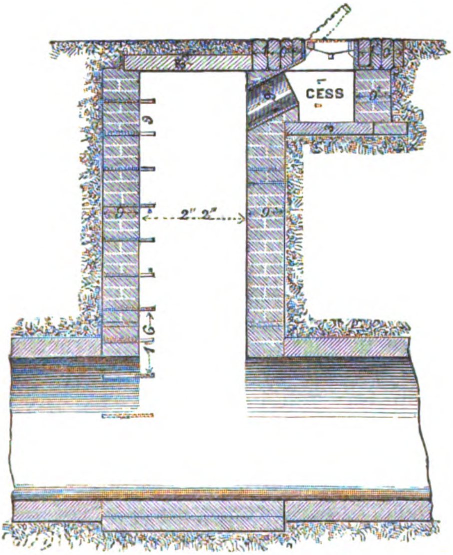
The sewers are connected by curved junctions, or bellmouths, the curves being laid at a steeper inclination.

The subsoil through which the sewers in the higher parts of the town had to be laid is marl, rock, &c.; but in the flat part, where most of the new sewers were required, it is a level deposit of mud, or clay, more or less hard, naturally about the level of high water of ordinary spring tides, and 4 feet or 5 feet below high water of extraordinary spring tides, but covered, for a depth of about 6 feet, with ships' ballast—stones, gravel, and sand—or with clay from the excavations for the docks, &c. In some parts, at a depth of about 10 feet from the natural surface and 16 feet from the present surface, a layer of peat 6 inches or 9 inches thick was found; and in places, where the brickwork would have rested on it, the peat was removed and concrete was substituted. The construction of sewers in this flat district was found to be easy, where the ground was dry, and the brickwork could be executed immediately on the completion of the trench, which was cut by a template exactly to the shape; but where the trenches were acted on by land, or tidal water, difficulties necessarily arose, which had to be overcome in various ways. Generally, owing to the looseness of the ballast, and the water it contained, the trenches had to be well strutted and lined with planks, which were driven down vertically as the workmen removed the ground, while other men were employed in baling, or pumping the water, which ran in from the ballast, or the old drains, and sometimes from the river at high tide. In one of the large sewers, which was constructed to a point near the river, before the outlet works were completed, the contractor for some time used a syphon to discharge the water into the river, when the tide would allow. The sewer along Church Street, which is 573 yards in length, and from 3 feet to 10 feet below high water of spring tides, running nearly parallel to the river and only from 33 yards to 90 yards from it, is in difficult ground. The street, for a considerable distance, is only 14 feet wide, with houses on one side, and a railway carrying heavy mineral traffic on the other, the rails being only

18 feet from the houses. The sewer is from 8 feet to 15 feet below the surface in a soft clay. There are several imperfect old sewers and drains across the line of this sewer, and these, added to the loose character of the ground, for several feet below the surface, and in some parts below the range of the tide, rendered it difficult to keep the trenches clear, and in shape. The most effectual plan was found to be to prosecute the work promptly and vigorously during neap tides, which scarcely affected the trenches; and in order to save the houses, of which the foundations were in some cases on the ballast, only a little below the surface, the contractor was allowed to tunnel portions of the work. In filling the trenches, the clay required careful ramming, to prevent the settlement of the adjacent buildings. The greater part of the work being in open cutting, and the remainder in tunnel, the gas and water pipes which ran along this narrow street, near to, or over the sewer, were broken by the unequal subsidence of the ground. As a rule, tunnelling and building brickwork at night were forbidden, the Author having found, in numerous instances, that, when underground, or working at night, bricklayers would, without the knowledge of their employers, put in very rough work,—bricks without mortar, or even one ring of brickwork instead of two. In one case the Author found a bricklayer laying the crown of a sewer in a tunnel, under a passenger and mineral railway, in bricks without mortar, although the mortar yard was but a short distance from the spot; and several instances came to his knowledge, where one ring of brickwork was inserted instead of two. In sewer works where the sizes are not large, and the work is progressing simultaneously at a great many places, it would be vain to attempt to watch every brick put in, if tunnelling and night-work were allowed; and the Author has consequently found it desirable to have, as far as possible, open cuttings and brickwork executed by daylight.

As previously referred to, the sewers near two of the outlets, have, for a period of about three hours at spring tides, to act as reservoirs, and ventilation is then more than usually important, to prevent the noxious gases from being forced up through private drains into the houses, where the house drains are not properly trapped. The ventilation of the sewers is effected, and means of access to them is secured, by a large number of manholes and ventilators combined, which are placed in open parts of the centre of the roads and streets. These consist of a square shaft carried up from the sewer to near the surface, and covered by a flagstone, and then by a thin layer of the macadamized metalling of the road. Close to the shaft a small cess is constructed of brickwork in cement, with a flagstone bottom; and a stoneware pipe, 9 inches in diameter, is laid from the side of the cess, 6 inches above the bottom, through the brickwork to the shaft: a strong iron grating weighing 1 cwt. 3 qrs. 7 lbs., hinged and with a notched surface, being fixed over the cess (Fig. 3). By this arrangement any rubbish falling through the grating is caught in the cess, and may be removed without difficulty; the grating also indicates exactly the position of the manhole. Ladder irons are built in the brickwork of the shaft, to facilitate ingress and egress. These combined manholes and ventilators are found economical, costing £4. 10*s*. complete, and are suitable to such towns as Newport.

Fig. 3.



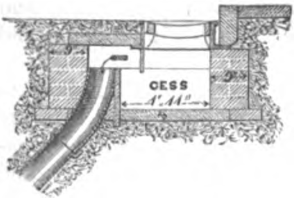
Manhole and Ventilator combined.

During the construction of the sewers glazed stoneware inlet pipes, 9 inches, or 6 inches in diameter, were inserted in the side walls, for connecting house and street drainage; these pipes were specially made, so that when fixed obliquely in the brickwork, with a proper fall, the socket end was outside the sewer, and the other end was flush with the inner face of the brickwork. They were generally placed opposite every house, or at points fixed on by the Engineer's inspector. In a large number of cases the house drainage was carried on simultaneously with the sewers; in others, marks were made to indicate the position of the pipes, and the house drainage was effected subsequently. Usually a separate drain, 6 inches in diameter, was constructed for each house, or a drain

9 inches diameter for two, or more houses, belonging to the same owner. Cesspools were cleared and filled up, and all sewage matter was allowed to pass through pipe drains into the sewers; water traps being placed at the commencement of the drains and in the closets to prevent the rising of effluvia. The junction pipes not used for house drainage, although partially stopped with a slate, or tile, afford an inlet for water, and thus drain the land several feet below the level of the cellars.

The gully grates for street drainage (Fig. 4) are of cast iron, 21 inches by 17 inches at the surface, hinged and slightly concave in the line of the bars, with a vertical flange which, with the stone and brickwork in cement of the cess for catching the silt, over which it is placed, forms a water trap to prevent any effluvia from rising from the sewer. The casting weighs $2\frac{1}{4}$ cwt. A pipe 6 inches diameter is laid at a steep inclination into the sewer. The gully grate, cess, and drain complete cost £3.

Fig. 4.



Gully Grate and Drain.

The Author's estimate for the works was £13,838, and the tenders, nine in number (the highest and the lowest being from London contractors), ranged from £11,893 to £16,797: the lowest was accepted, and the contract was closed at £11,862, that sum paying for 12,500 lineal yards of sewers, with manholes, ventilators, gullies, and outlets; instead of 11,900 yards as in the contract. This saving was effected by reducing the thickness of the brickwork in many cases, after ascertaining the nature of the ground, by using mortar instead of cement in the inverts, and by otherwise carefully economising the construction. The works were completed at a cost about 14 per cent. under the Engineer's estimate, which latter was less than the average of the tenders: but these facts are not mentioned with the view of encouraging the practice, so disastrous in its results, often adopted by Local Boards, of accepting the lowest tender, without due regard to the capability of the contractor to perform his engagements. In this case the reputation and experience of the contractor justified the course pursued, and on the completion of the contract, the Local Board of Health passed a resolution expressing their perfect satisfaction with the works.

During the execution of these works 1,250 yards of sewers with manholes, ventilators, gullies, &c., were constructed for the Tredegar Wharf Company, under the direction of the Author. Sewers were also made by him for other landowners, in ground about to be built upon; and subsequently works have been constructed by Mr. Conyers Kirby, Surveyor to the Board, on plans prepared by the Author, for the drainage of a small portion of the borough on the east side of the river where the population is increasing.

The Local Board has only partially carried out the repairs and cleansing of the old sewers, which formed part of the original plan; and in some instances the new sewers now receive from the old, which are defective, quantities of rubbish of almost every description, including stones, pieces of iron and tin, boots, &c.; but notwithstanding this, Mr. Kirby states, that the new sewers, most of which have now been in use about four years, act well, and cost the Board and landowners almost nothing in repairs and cleansing.

The rate of mortality in Newport has decreased from 30·3 in a thousand, before the Public Health Act was applied in 1850, to rather less than 20 in a thousand, for two years ending Michaelmas 1861, which latter rate is below the average of England and Wales; and no doubt this very large decrease of deaths is, under Providence, to a considerable extent due to efficient drainage and water supply, the prevention of overcrowding, and other sanitary measures.

The Paper is illustrated by a Plan of the town of Newport, and by a series of diagrams, from which Plate 4 and woodcuts, Figs. 3 and 4, have been compiled.

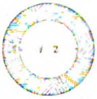
Mr. **Fulton** stated, through the Secretary, that after upwards of an additional year's experience, since writing the Paper, and after a practice of eighteen years in sanitary engineering at Liverpool, and in Dundee, he was fully convinced, that with properly-constructed sewers, no ventilation was requisite. This might seem a startling assertion, but having had a length of not less than 30 miles of main sewers, and nearly as many miles of branch drains, all closely trapped, in use for several years, without a single complaint being made regarding foul emanations from them, was a proof of the correctness of his position. The sewers were kept free of all silt, except sand, by the flow of the ordinary sewage and rainfall, regulated by flushing gates, so that their perfect cleanness, so far as any sewer could be called clean, was insured; or, to put the matter in another form, no putrescent substances were retained in the sewers, or drains, to fill them with deleterious gases, and to poison the inhabitants. Therefore, there did not exist the slightest necessity for the ventilation of such sewers and drains.

Mr. A. **Bassett** remarked, through the Secretary, that being well acquainted with the district of Newport, and particularly with a large extent of wharf and other property, on the River Usk, belonging to Lord Tredegar, he had opportunities of forming an opinion on the utility of the drainage scheme executed by Mr. A. Williams, and it afforded him much pleasure to state, that the works had proved to be most satisfactory, both as regarded economy and efficiency. He had never heard of any complaint having been made with reference to the discharge of the drainage water into the River Usk. The large river area, coupled with the rapid flow of the tide, precluded any ill effects arising from this mode of drainage.

Mr. **Thos. C. Thorburn** (Borough Surveyor, Derby), observed, through the Secretary, that he did not think the drainage works of Dundee would be found to work satisfactorily, without efficient means of ventilátion. He was persuaded that the light sewer gases would force themselves through the inlets, or imperfections of the pipe-joints, at the higher levels, which would in most cases be under houses, and therefore would be doubly objectionable in a sanitary point of view. The arrangements for flushing, at Dundee, appeared to be ingenious, but they must involve considerable expense in labour. Such complicated works as town sewers generally were should be arranged on the most simple principle, and be made, as far as possible, self-acting. The flushing of town sewers was absolutely necessary if they were to be kept clean, without resorting to the old method of breaking up the surface of the roads, or sending men up the sewers to clear them by hand. At Derby the whole of the sewers were kept clean by

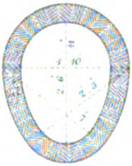
NEWPORT DRAINAGE.

Fig. 1



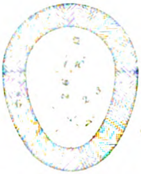
Brickwork, per Lin. Yd. 5½ C. Ft.
Cost 7/7

Fig. 2



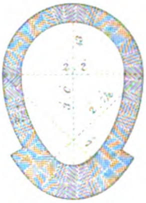
Brickwork per Lin. Yd. 9 C. Ft.
Cost . . . 10/11½

Fig. 3



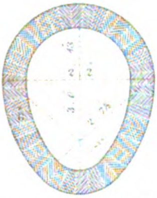
Brickwork per Lin. Yd. 12⅔ C. Ft.
Cost 13/10

Fig. 4



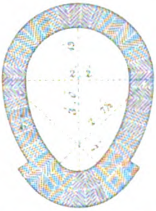
Brickwork per Lin. Yd. 14 1/16 C. Ft.
Cost . . . 15/-

Fig. 5



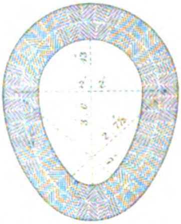
Brickwork, per Lin. Yd. 14⅔ C. Ft.
Cost 15/6

Fig. 6



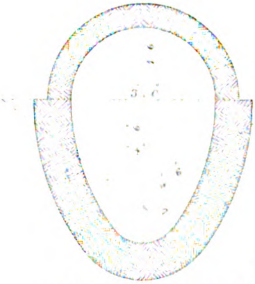
Brickwork per Lin. Yd. 17 C. Ft.
Cost 17/2

Fig. 7



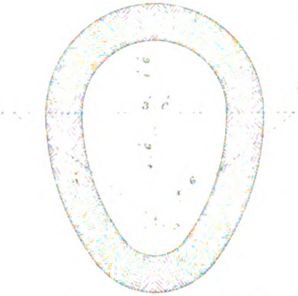
Brickwork, per Lin. Yd. 23⅘ C. Ft.
Cost 22/-

Fig. 8



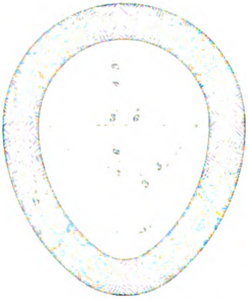
Brickwork, per Lin. Yd. 27 7/16 C. Ft.
Cost 28/4

Fig. 9



Brickwork, per Lin. Yd. 32 9/16 C. Ft.
Cost 31/6

Fig. 10



Brickwork per Lin. Yd. 33⅔ C. Ft.
Cost 35/-

The above Prices include Cuttings 10 Feet deep in Figs. 4 to 7, 12½ Feet in Fig. 8, 13¾ Feet in Fig. 9, and 15½ Feet in Fig. 10.

Ins 12
0
5
10 Feet

Minutes of Proceedings, Institution of Civil Engineers, Vol. XXII. Session 1862–63.

A. WILLIAMS DELT KELL BROS LITHO

flushing, by penstocks fixed at the river side above the weirs, and by numerous cisterns constructed at the upper end of the collateral and branch sewers, filled with water from the mains of the Waterworks Company. No doubt this involved expense; but, on the other hand, labour was saved, and he believed the public were fully compensated by the more efficient working, and by the sewage being carried completely away from the town to the outlets. In other respects the arrangements for the drainage of Dundee, if carefully carried out, would probably work satisfactorily.

Mr. Williams appeared to have designed the works of drainage at Newport with great discrimination, and if they had been executed with care, they would no doubt act well. He did not, however, entirely agree with the Author in the limit to which he recommended the use of stoneware pipes, for house-drainage, as long experience had convinced him that they might, with advantage and economy, be used for collateral sewers, and for the upper ends of main sewers, where the flow of sewage was small, and adequate means of flushing were provided. He did not, however, recommend the use of stoneware pipes for sewers of any description, without sufficient power for water-flushing being in every case provided, especially where debris was liable to be washed from the streets and roads into the sewers.

Mr. R. Rawlinson said the description of the works at Dundee was clear and full; but there were some remarks which deserved special notice. He would direct attention, in the first place, to the amount of sewage discharged by the outlet sewer, which was stated to measure, in dry weather, 2 feet, and, during storms, 6 feet in depth; and that the velocity of the discharge was in the former case 65 feet per minute, and in the latter 116 feet per minute. He had looked over the calculations, and thought there must be a mistake; unless there was some element which did not appear in the Paper. He believed the velocity would be much higher for the gradient given, and the depth of water in those sewers; at least he had found it to be so in sewers he had constructed.

The principal point, however, to which he wished to call attention was, that although it was stated that the sewers at Dundee had been designed to act entirely without ventilation, and the Author asserted that ventilation was not required; yet, with apparent inconsistency, in another part of the Paper, he had spoken of having trapped certain gullies, to prevent the sewage gases escaping into the streets and houses. Mr. Rawlinson had a large experience in sewer construction, and he contended that it was dangerous to lay down a system of sewers over an entire town, without in the first instance providing, as part of the scheme, for the fullest and freest ventilation, at all parts of a town; but it was generally most necessary at the upper and higher levels. Sewage gases, being lighter than atmospheric air, flowed upwards, while the sewage itself flowed downwards, and as the velocity of the discharge of sewage water downwards would be in proportion to the gradient of the sewer, the flow of sewage gases upwards would also be in proportion to the gradient. Therefore, a town having a naturally steep gradient, required the fullest means of ventilation; and so far from its being easy to sewer such a town, he held, if proper means were not taken to provide for ventilation, the Engineer was liable to leave that town worse than he found it. Within his own knowledge, disease had broken out in well-sewered districts, which was traced to a connection of house drains with unventilated sewers; and in those cases the highest portions of the towns suffered most severely. He thought the authorities at Dundee should not rest satisfied with what had been already done, nor until the work was completed by a proper ventilation of the sewers. Mr. Fulton seemed to infer, that sewers which wanted ventilation had been badly constructed. Mr. Rawlinson, on the contrary, held, that if such sewers were sweet, they must have been badly constructed; and that there were joints and crevices which allowed the gases to escape; because, with a perfectly tight sewer, the gases must make their way to the upper extremity, and have a tendency to find exits into houses through the house drains. The method of cleansing sewers, proposed by Mr. Fulton, was very similar to a system invented by the late Mr. Richard Blades, and used by him at Liverpool; it had also been introduced to the notice of the Metropolitan Board of Works. He thought it right to mention this, because credit ought always to be given to those who had the priority in any useful invention.

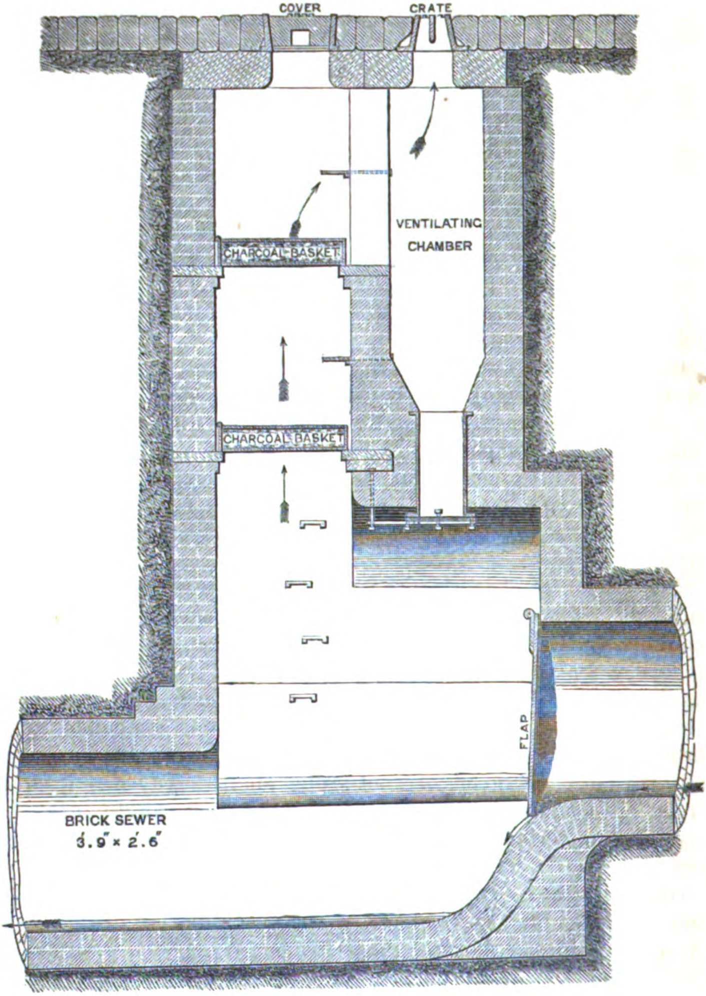
Mr. Alfred Williams had presented an able description of good and useful works executed at Newport, Monmouthshire, where ventilation had been adopted. He did not quite understand what was meant by the remark, that it was not considered advisable to use stoneware pipes as main sewers, but that it was preferable to adopt a sewer of sufficient size for men to traverse. He thought any Engineer in sewering a town, ought to banish from his mind, at once and for ever, the necessity of constructing sewers sufficiently large for a man to pass through, unless those dimensions were required to discharge the sewage flowing into them, and should rather endeavour to design such a form of sewer as would be absolutely certain to discharge the contents derived from the upper extremities and from all the tributaries, and to keep the sewers clean and sweet. He could mention instances, in his own practice, where sewers had been constructed so as to act in the most efficient manner, without incurring the additional cost of making them larger than was necessary, merely for the sake of saying at the conclusion of the work, "that they had a sewer large enough for a man to go through." He could point to dozens of miles of sewers which had been in operation a sufficient length of time to subject them to the severest test, without any instance of failure from choking up, or requiring hand-cleansing. The sections of the Newport sewers (Plate 4) were certainly of the most approved forms, and the bricks employed there were well adapted for the construction of such sewers with economy. Looking at the section, Fig. 8, Plate 4, it appeared that the internal dimensions of that sewer were 4 feet 6 by 3 feet, and that the brickwork of the invert and of the sides consisted of a double ring, 9 inches in thickness, while in the crown there was a single ring only, 6 inches in thickness. He did not know what plan had been followed at Newport, but in his own practice he should have set the two top courses of the thicker part of the work as 'headers,' so as to bond the two lower rings together, and to give a fair start for the single ring. In fact, in every instance where there were two rings of brickwork in the invert and sides, he insisted that there should be two rows of 'headers' at, or about the springing, so as to bond and tie the work together, where the arch commenced. The method of ventilating a sewer at Newport was good as far as it went; but he thought it was imperfect in this respect, that the manhole shaft was not available, without removing the flag which covered it, and thus breaking up the street.

The system of ventilation he had adopted was shown by Fig. 5, page 288. There was a side chamber; but instead of covering the manhole shaft with a flagstone, which was difficult and expensive to remove, when access to the sewer was desired, it was finished with a manhole cover, which formed the street surface, and did not allow air to pass out; so that the sewer gas was compelled to rise through two, or more charcoal screens, or filters, before passing into the side chamber, or ventilating shaft. Any dirt from the street, falling into the ventilating chamber, was caught in an iron box, at the bottom of which there was a slide, so that the dirt could be readily removed whenever necessary.

In a hilly town the whole system of sewage should not be so connected together as to permit of the accumulation of the sewage gases in the higher parts of the district. Where the gradient was steeper than 1 in 200, and a sewer was, say, one mile in length, it should be divided by steps, or falls, and there should be a flap valve upon the upper, or higher discharging end of the sewer; with at least two ventilating grates at that point, so as to insure thorough ventilation.

It was to be remarked, that the systems of sewerage, both at Dundee and at Newport, discharged into rivers. It was frequently necessary to carry the outlet of a sewer to a river, having a low summer level, and a high, or flood level. It was

Fig. 5.


COVER
CRATE
VENTILATING CHAMBER
CHARCOAL BASKET
CHARCOAL BASKET
FLAP
BRICK SEWER
3.9" × 2.6"

Manhole, Tumbling Bay, and Double Ventilating Arrangement.

neither advisable, nor always practicable, during flood times, to carry the whole of the sewage, if the quantity was considerable, down below the summer level. Figs. 6 and 7 (p. 289) showed the arrangement he had executed at Windsor Castle, where formerly

Fig. 6.

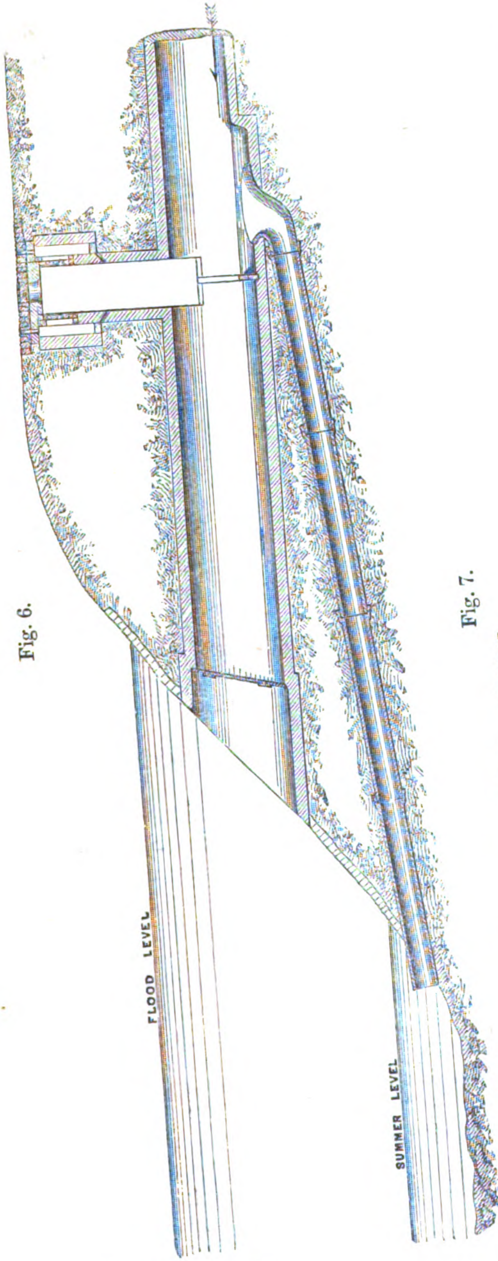
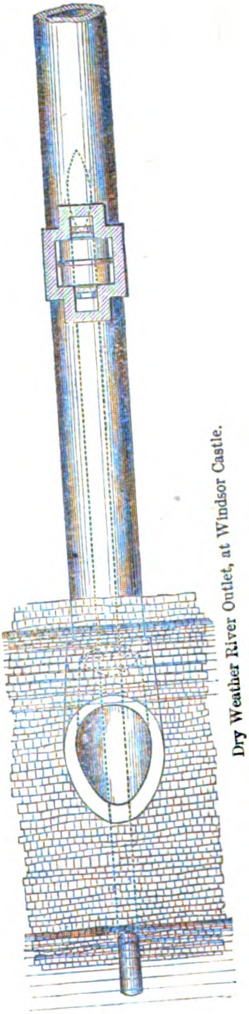

FLOOD LEVEL
SUMMER LEVEL

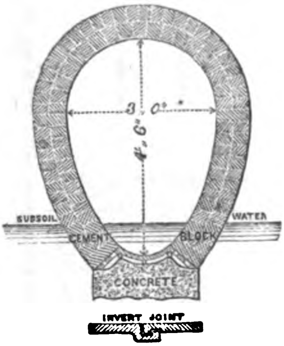
Fig. 7.



Dry Weather River Outlet, at Windsor Castle.

a large brick sewer discharged itself into the Thames, close to the Queen's private walk, and was a source of nuisance. By fixing a cast-iron pipe at the bottom of the sewer, and putting a slight dam in front of the junction, all the ordinary sewage was discharged by the iron pipe below summer level, so that the sewage was never thrown into daylight. The brick sewer above took away all excessive storm waters, and there was no danger of bursting, or other difficulty. He found a sewer 4 feet high and 3 feet wide might be required for flood, or storm waters; but that an iron pipe 12 inches diameter would probably discharge the ordinary flow of sewage for three hundred days out of the year, and when there was anything more than the pipe would take off, it would be in extreme dilution, and the river itself would be in flood, so that there would be a minimum amount of nuisance.

Fig. 8.



Main Outlet Sewer, West Ham.

The main outlet sewer at West Ham (Fig. 8) was 4 feet 6 inches in height by 3 feet in width. It had a cast-iron invert, which was laid for about half a mile, at the level of low water of spring tides, and then for 2½ miles with a fall of 3 feet per mile. Of course the outlet was obtained by pumping. The surface of the ground, under which that sewer was laid, varied from 10 feet to 12 feet below high water in the Thames, and the subsoil was so porous, that with a portable engine within 10 feet of the work, the water could not be pumped below the line shown on the section (Fig 8). Consequently, he had to devise an iron invert, which the workmen could put into its place in the trench under water, by feeling only. The arrangement of the joint was such that there was a certainty of the plates falling into place, and each could be raised by the side flanges, and be rammed below with gravel, or clay. Upon this invert plate cement blocks were laid to above the water line, and the other portions of the sewer were built in the ordinary manner. About 3 miles of that sewer had been in use for nearly two years, and there was no difficulty in keeping it clean. The velocity of discharge in that sewer, which had its invert on a level, was higher than that which had been given in the Paper on the Drainage of Dundee, for a depth of 2 feet of water and a gradient of 1 in 400. The velocity was due to the surface gradient, or head. Means of flushing were provided, and the only fall was the grade of the surface.

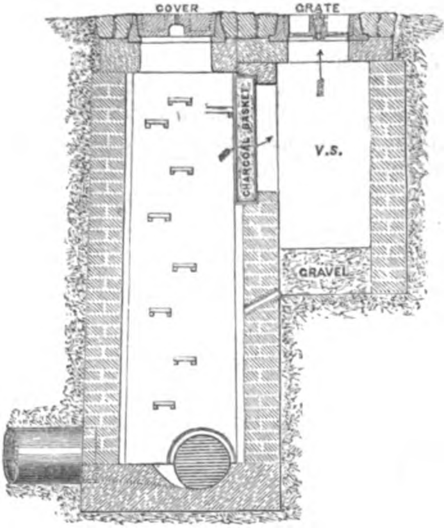
The mode of forming sewer junctions by bent pipes was, he thought, defective. A better plan was at the option of the Engineer, and he had requested Mr. Doulton to send specimens of side junctions, suitable both for 9-inch and for 4½-inch work, which, he explained, formed part of the brick sewer, whatever size it might be; the blocks being built in with the work wherever junctions were anticipated. He also directed attention to an earthenware disc plate, which might be secured either with clay, or cement, and was intended to be put on the openings as the sewer proceeded, to prevent extraneous matters from being introduced. Slate, or flag coverings were neither so cheap, nor so perfect, nor so handy to use. The ordinary invert block afforded great facilities in accelerating the work, and in use, secured the scouring action of a pipe having that diameter, whatever the dimensions of the sewer might be.

The drawing (Plate 5) gave the particulars of various sewers, their forms and sizes, the number of bricks, and of the cost of each section per lineal yard, together with the prices of the various materials. These were not merely assumed figures, but were the actual prices at which sewers had been executed, at Berwick-upon-Tweed, Carlisle, Chorley, Lancaster, and other places. It might be useful for reference, and in every instance it would be seen, that double courses of bonding bricks were put in at, or near the springing, to insure the rings being tied together.

As the question of town sewerage was of daily increasing importance, he had been at some trouble to bring these matters forward, because he wished to give the fullest information in his power; and he thought young Engineers would do well to pay attention to the subject in all its bearings. He had adopted several leading principles, which he would briefly refer to. In the first place every sewer should be laid out in an absolute right line from point to point. He laid stress upon that, because in examining old lines of sewers, he found they invariably took the course of the streets under which they were constructed. To set out a sewer in a straight line surface sight rails were necessary, so as to 'bone' the invert level. The main sewer at Brighton, built within the last ten years, by a former surveyor, under the old Commissioners, was proved on examination to be most irregular both in line and level. This he apprehended must have arisen from the sewer having been built in short lengths, and without sight rails, or any proper levels. Then again at every change either in line, or in gradient, there should be a manhole, or a lamphole, to afford the means of access to the sewer from the surface. At all manholes, and at many of the lampholes, means of ventilation should be provided, such as he had explained. A chamber should be formed at the side of each of these ventilating shafts, to catch detritus from the roads; and the ventilating grate should be over it, and not directly above the crown of the sewer.

Between the side chamber and the shaft, charcoal filters should be fixed, so as to deodorise the foul gases, before passing into the streets. Care must be taken, that ventilating openings should not be direct down into the sewer, as was the case with the great part of the sewers of the Metropolis, where shafts were carried up direct from the crown of the sewer, and the ventilating grate was put directly above it, thus admitting foul gases into the streets without deodorisation, and allowing stones and mud from the macadamized roads to fall into the sewer below, and to form an obstruction upon the invert, which was a cause of great mischief. The sooner this state of things was remedied, the better it would be for the Metropolitan drainage. It was impossible to carry out the grand scheme of intercepting drainage beneficially, if the tributaries were left in an imperfect condition. He ventured to mention his views on this subject, as he thought the first effect of the operation of the intercepting sewers would be, that water would be abstracted from the sewers which were now diluted with it; the washings of macadamized roads, which formed a good disinfecting material, would be taken away with the flood water, and in the intermediate districts, where there were great lengths of foul tributary sewers, there would be deposits of putrid matters; and with the ventilating grates opening directly into the streets, one of the first effects, during a hot and dry summer, would be to raise

Fig. 9.



Manhole and Ventilating Shaft.

PLATE [illegible]

SECTIONS OF BRICK SEWERS.

Fig. 1a

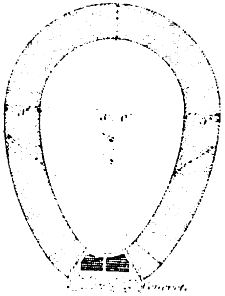


Fig. 1b

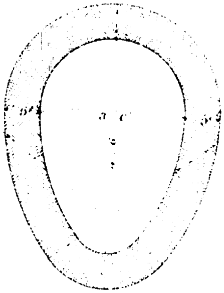


Fig. 2b

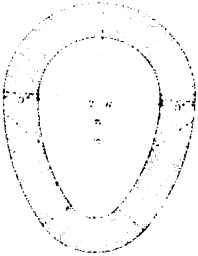


Fig. 2c

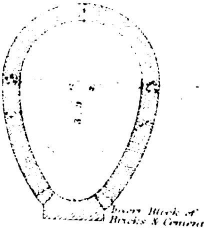

Invert Block of Bricks & Cement

Fig. 2d

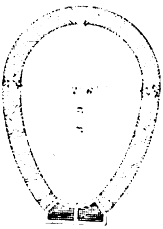


Fig. 3b

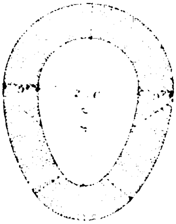


Fig. 3c

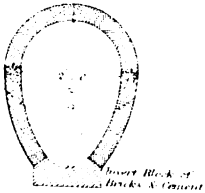

Invert Block of Bricks & Cement

Fig. 3d

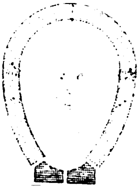


Fig. 4b

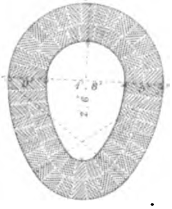


Fig. 4c

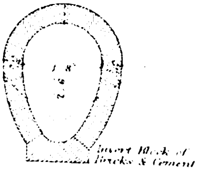

Invert Block of Bricks & Cement

Fig. 4d

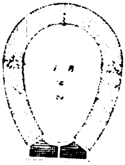


Fig. 5b

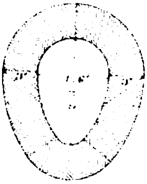


Fig. 5c

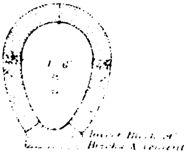
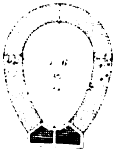

Invert Block of Bricks & Cement

Fig. 5d



Institution of Civil Engineers Vol. [illegible]

the rate of mortality. The Registrar-General would find it out, and record it in his Reports on the State of the Metropolis, unless some prompt precautions were taken, as it would be a serious evil to abstract the flood water which now diluted the foul matters in the sewers, unless provision was made to counteract such effect.

His reason for laying out sewers in right lines, was because he had found in practice, that to insist upon straight lines of sewers, and an absolutely true gradient, was more than equivalent to putting an inspector on the work. He would defy a contractor to scamp work if it was required to be true in line, both vertically and horizontally. Practically he never allowed the curves of junction to exceed 22½ degrees.

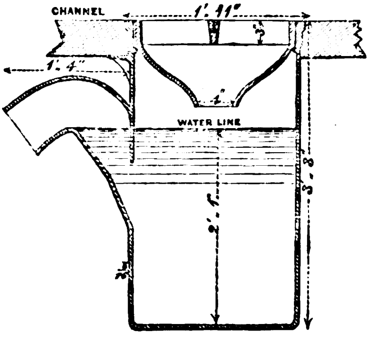
Sewers of unequal dimensions should never be level at the inverts. It was safer, as a rule, that they should be even at the crown,—that the tributary drain should have an extreme fall at its junction with the main sewer. The fact of one sewer being made larger than another, implied that the former would have more work to do; and if the sewers were joined with level inverts, the large sewer would dam back the sewage in the smaller tributary, and prevent its being flushed out. He had found that where pipe drains were brought into a sewer with level inverts, the pipes became rapidly choked up, as the sewer water was dammed back for one-half, or two-thirds of their diameter, and sediment which had poured into them had no opportunity of getting out. But if the invert was raised above the ordinary flow of the main sewer, the solid ingredients might be diluted, and be flushed out, without still-water lying in the tributary drain. A tributary sewer would be better with less gradient and a free delivery. Sewers might be made to discharge large weights of material which had passed through the gullies. As an illustration of this he might instance the Birmingham sewers. The amount of sediment at the outlets of those sewers was not less than 500 tons per week, or 25,000 tons per annum, which was almost equivalent to the weight of the metal put upon the roads, as Birmingham was macadamized throughout all the streets, and there were only very few paved channels. Whenever there was a heavy fall of rain, large quantities of the ground-up materials of the roads were carried into the sewers, which passed through them, and collected at the outlets.

At Carlisle, the main sewer had a fall of 1 in 700, for a length of a mile and a quarter; it was liable to be flooded frequently in the course of a year, and at times the freshets and floods rose 18 feet, or 20 feet above the level of the invert, and 10 feet, or 12 feet above the surface of the ground where the sewer was built. That sewer had been in operation for six, or seven years, without requiring any outlay for hand-cleansing, and without any extreme power for flushing, but simply by due attention being paid to the arrangements at the manholes. At every manhole there was a groove in the brickwork to receive a stop plank, by which the sewers could be flushed out in sections, either by accumulated sewage, or by the admission of water from the Waterworks.

The question of fouling of rivers, by allowing undiluted sewage to pass into the nearest available water courses, was a matter of serious importance. It was a practice which the legislature should be called upon to put a stop to; but in saying this, he hoped that advocates would not arise for the abolition of the system of sewerage, because certain rivers had been fouled, and injuries done, for which apparently there had been no remedy up to a certain time. That which was of the greatest value in the consideration of this question was that greatest blessing to any community,—healthy human life. Modern civilization had been the means of massing populations together in towns: a town population could not exist and enjoy good health without some efficient, constant, and unceasing system of removing all the soil refuse from the midst of that mass of human beings. Schemes had been propounded for the sanitary inspection of water-closets, and house-to-house visitations; and various plans had been devised, to save what was conceived to be a valuable manure, in a form other than its being passed away in water. But his experience led him to the conclusion—that the cheapest element to remove soil refuse was water, and that the readiest method of doing it was by a proper system of sewers. It was quite possible that this could be done without committing any injury whatever; because chemistry could be brought to their aid. If it was not worth while commercially to pump the fluids and the solids, for the purpose of appropriating them to agricultural uses, then the solid matters should be removed by deposition and filtration, and the liquids should be deodorised, before being discharged into the rivers and water courses. In the year 1859, the River Thames, within the Metropolis, became a foul stinking stream, and the rivers in the vicinity of Manchester were foul beyond the powers of language to describe. That was also the state of some of the rivers in the manufacturing and thickly populated districts of the West Riding of Yorkshire. It must not, however, be thought, that because these evils existed, the sewers were in fault. They were only imperfect appliances at present, but were still a great improvement on the old cesspool system. He believed they were on the eve of a satisfactory solution of this problem. The land, beyond all question, was the place to which the soil refuse should go, and if the authorities of a town could not dispose of it at a profit, so as to obtain a return for their outlay, they ought to be compelled to incur the necessary expenditure, for carrying it to some place, whence it could be beneficially applied, without creating a nuisance, and pay the necessary cost.

Mr. J. NEWTON contended that no system was perfect which permitted accumulations in the sewers; for if the velocity of the flowing sewage was insufficient to prevent the deposit of sand, grit, or other insoluble substances, such matters ought not to be allowed to enter the sewers, and by suitable gully traps and cesspits this might be easily accomplished.. At Dundee, the main outlet sewer had a fall of 1 in 400 only, whereas some of the other mains had gradients varying from 1 in 600 to 1 in 700. As the scouring power was in proportion to the velocity, and the velocity, with like gradients, was in proportion to the amount of flow, this outlet might, with advantage, have been made much flatter than 1 in 400, and the fall, thus economised, have been used for augmenting the fall of the subsidiary mains. The gradient and the section of a sewer at the invert ought to be carefully adjusted to the probable average flow of sewage through it; and when this was done, it would very rarely be found that silting occurred, or even that flushing was necessary. In regard to street gullies, he directed attention to one entirely of cast iron which he had adopted (Fig. 10). It weighed 4 cwt. 2 qrs. 14 lbs., and, at six shillings and three-pence a cwt., cost £1. 9*s*. A smaller size, weighing 3 cwt. 1 qr., cost at the same rate, £1; whilst the expense of fixing, or of removal did not exceed two shillings each. The efficiency, cheapness, and durability of this form of gully had induced him to use it exclusively, and during the last five years, he had fixed upwards of sixteen hundred of them in the borough of Preston.

Fig. 10.



Street Gully, as used at Preston.

There was still a diversity of opinion amongst Engineers, as to the proper size of sewers. His own experience showed, that in purely urban districts a rainfall of 1 inch in half-an-hour ought to be provided for. Thus, on the 29th of July, 1857, he registered at Preston ¾ of an inch of rain in thirty-five minutes, and on the 8th of October, 1861, nearly the same depth in thirty minutes. On the latter occasion an egg-shaped brick sewer, 4 feet 9 inches high by 3 feet 2 inches wide and 300 yards in length, with a fall of 1 in 156, carried away this water from a closely built and densely populated district containing 117 acres. In another part of the town, which was also built upon and which contained 85 acres, a sewer 3 feet 6 inches high by 2 feet 4 inches wide, with a fall of 1 in 75, carried off these storms, without causing any damage, or without the water rising in the cellars, which were generally from 1 foot to 2 feet above the soffit of the arches. In both cases, however, the sewers were under pressure, as on the first occasion the water rose 18 inches, and in the other case 1 foot in the manhole shafts. These examples showed, that the sewers of Preston were not too large, and as most of the tributary mains ran nearly full on these occasions, and had never proved insufficient, they indicated the sizes required generally under similar circumstances. Almost all the rainfall, in the districts alluded to, flowed direct into the sewers, every house being drained, and but few receptacles existing for retaining the water. The sewers were constructed in straight lines, or on easy curves, and all branch drains were connected with the mains at angles of 45°. In ordinary town districts, calculating upon a maximum fall of rain of one inch in half-an-hour, and that it all passed directly into the sewers, he believed the following proportions would prevent silting, if the district was thickly populated, and the house drains were connected with the sewers:—

Diameter of Sewer.	Inclination.	Drainage Area.
Inches.		Sq. Ft.
6	1 in 50	200
9	1 in 100	400
12	1 in 150	650
15	1 in 200	1000
18	1 in 250	1400
21	1 in 300	1800

In intercepting sewers, where the ordinary flow was greater, and in large mains, an ordinary velocity of 1 foot per second would be amply sufficient to scour the invert, without any artificial flushing. As a general rule, he preferred the egg-shaped section for sewers, but where the inclination was such, that the velocity of the flowing sewage would not allow of silting, the circular form was preferable, because its discharging power was greater, when the flow was a maximum, and the cost of construction was less.

The form and construction of the brick sewers at Newport appeared to have been well considered; but there were many places in which a smaller tube than 14 inches in diameter would have sufficed. In such cases a 6-inch, or a 9-inch pipe would have effected a considerable saving in expense; in fact, at least one half might have been saved, and the efficiency of the system would have been improved. Although the advantages of good sewers, both in a moral and physical point of view, were undoubted, it was desirable not to be too sanguine in anticipations as to the results. Mr. Williams stated, that the mortality of Newport had been reduced from 30 per 1,000, in 1850, previous to the adoption of the Public Health Act, to less than 20 per 1,000 in 1860 and 1861. On reference to the Registrar Generals' Report he found that in—

1851,	the mortality	was	23·1	per 1000.
1852,	„	„	25·5	„
1853,	„	„	22·6	„
1854,	„	„	26·2	„
1855,	„	„	25·2	„
1856,	„	„	26·4	„
1857,	„	„	23·3	„
1858,	„	„	33·3	„
1859,	„	„	24·1	„
	Average . .		25·5	„

Mr. Williams might, therefore, with equal accuracy and reason, have said it was reduced from 22·6 per 1,000 in 1853, to less than 20 per 1,000 in 1860 and 1861. The mortality of a district was influenced by so many causes, and fluctuated so much, that conclusions should not be drawn from a short period of time: nevertheless he was satisfied that much good must necessarily arise from such works.

Mr. W. Merry remarked, that some of the observations which had been made reminded him of the dogma of twelve, or fourteen years ago, that certain specific rules might be laid down to apply to every town in the United Kingdom. He dissented from that doctrine, and he regretted to find that such notions should still be entertained; because experience had shown that every town must be dealt with on its own merits. It was necessary to take the local circumstances into consideration, as there might be a variety of peculiarities appertaining to one town which did not exist in another. There were general principles which should be discussed before entering into the details. In the first place, with reference to the drainage of provincial towns,—it was said that the work was done at less cost than in the metropolis. The great point, in the system adopted at Dundee, appeared to be, that a length of 30 miles of sewers had been in use for years, without provision having been made for ventilation, and that no complaint was made of nuisance. It should at the same time have been stated how many houses in that borough had water-closets, what number of these drained into the sewers, and what proportion had 'middins.' He believed it would be found, that not more than one-third of the filth of the town got into the sewers. He had visited several large provincial towns which were drained upon this system, at probably one-half the cost of similar works in the metropolis, and he found that there were only water-closets in the first-class houses,—the houses of the middle and lower classes having 'middins,' the contents of which were removed periodically by the dust contractors, and were used upon the land. In such cases there was plenty of room in the rear of the houses for ventilation; but that system would not answer for London. This was further evident, by reference to the quality of the sewage, which in London might be compared to treacle in consistency, whilst in the country it was simply dirty water. At Paddington, which was considered an aristocratic part of London, there were about 800 acres of land on which there were 10,000 houses and 80,000 inhabitants, or an average of 100 to the acre. In other parts of London there were from 1,500 to 2,000 persons per acre. Recently plots of land at Paddington were covered with six-roomed houses; and on one estate, called Hall Park, containing an area of 3 acres, 235 six-roomed houses had been erected, with a water-closet to each house, the population amounting to 2,649 inhabitants. The sewers there, had a gradient of 1 in 480, and yet they required flushing, notwithstanding it had been stated that 1 in 600 was self-cleansing. Before arriving at conclusions on this subject, it was necessary to know the number of houses, the number of the inhabitants, the amount of the water supply, and whether each house was furnished with a water-closet which drained into the sewers.

Mr. RAWLINSON stated that Professor Way, who had analysed many different sewage waters from all parts of the country, found the analyses as nearly alike as possible. It was a mistake to speak of London alone as being a water-closeted town. At Alnwick, with 7,000 inhabitants, there was not a house without a water-closet. There was no necessity to provide duplicate sewers for surface flood water, in a system of sewers in provincial towns. The special features of every town should be studied, and the works be laid out with due regard to local peculiarities. Rules for sewers in the metropolis, or at Preston, or elsewhere, would not apply, except under similar conditions. In the town of Alnwick, having an area of 2,000 acres, the outlet sewer was 18 inches in diameter, with a fall of 1 in 400. It had been in use for ten years, although all the down spouts, yard grids, and street gullies communicated direct with the pipe sewers. Alnwick Castle, with several acres of area, was sewered by a 12-inch pipe, and that effectively. The town of Worksop was sewered by a 15-inch pipe outlet. In each case the flood water of heavy rain flowed over the surface, as it did before any sewers were made.

Mr. J. GRANT remarked that, the main sewers on the south side of the River Thames were all provided with ventilating shafts and side catch pits, each capable of holding about a cubic yard of matter, which prevented stones and mud from entering the sewers. Between each ventilating shaft and catch pit there was a semicircular opening, all the openings being of the same diameter throughout, to admit of frames filled with charcoal, or other deodorising material being afterwards fitted; and through these frames of charcoal the foul gases would have to pass, before being allowed to enter the atmosphere. In confirmation of the statement, as to the advantage of a supplementary pipe outlet to discharge at low water, he mentioned that he had carried out a similar arrangement, at Battersea, eight, or ten years ago, and subsequently at four, or five other outlets of the main sewers on the south side of the River Thames. He laid large iron pipes to below low-water mark, having flaps, or penstocks, to prevent the tide from entering at high water. This plan had been adopted at London Bridge, and at Waterloo Bridge, as well as at other places. He concurred in the opinion that, in laying out a system of sewers, every town must be dealt with according to the local circumstances and the peculiar features of the case. The character of the outlet, the rate of inclination, and the nature of the surface of the ground, the rate and the amount of the rainfall, the number of houses draining into the sewers, the extent of the population, and other things, all required consideration.

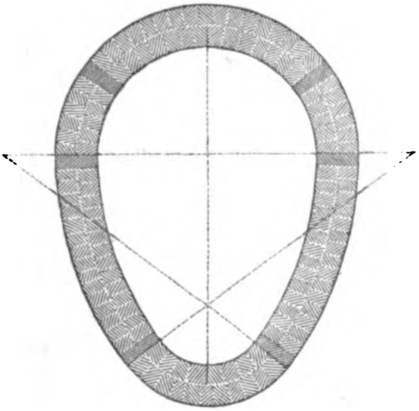
With reference to the question of cleansing sewers, he thought that the method adopted at Dundee was complicated and expensive; and that the plan pursued in the metropolis, which he had first practised at Richmond, was simpler and cheaper. In the pipe, or sewer a flap valve was fixed, which could be kept closed until a head of water accumulated. By this means the water could be backed up to any height that might be fixed upon; and when the valve was opened, the rush of water would clear away any deposit, including macadamized matter and stones.

Mr. RAWLINSON inquired whether the system of ventilation alluded to had been adopted at the west-end of London.

Mr. GRANT replied, that he believed it was likely to be adopted. It was simple, and effectually prevented stones and road mud from getting into the sewers.

Mr. Cockburn Curtis said, that the extension of the main sewerage works of the city of New York afforded an instance of the application to a particular case of the results arrived at, after a calm consideration of all the facts and arguments which had been recorded on either side, in the numerous blue books which had been published in England during the Administrative Contest popularly known as the 'Small Pipe' and 'Back Drainage' Controversy. In extending the sewerage of New York, the section adopted for nearly all the main sewers was similar to that shown in Fig. 11. As it appeared to be a well-established fact, that the maximum amount of rain which had fallen upon Manhattan Island, upon which New York was situated, had never exceeded one inch in an hour, the capacity of the sewers was adjusted to provide for that amount of flood water, in addition to the prospective maximum house sewerage flow of the several districts proposed to be drained. The material adopted was brick laid in cement, and the inner bottom of the sewer was plastered with cement, to make a uniform surface for about a foot in vertical height, or the lower courses were laid dry, according to the necessities of the locality. In keying the crown of the arch, no headers were allowed to be used, except when bricks were furnished of a particular shape, made expressly for that purpose. In all other cases, the inner and outer courses of stretchers were carried over separately, and each was keyed with slate, after the arch was turned. The streets in the modern part of New York were laid down in straight lines, and the main sewers were laid down as nearly as possible in the middle of the streets, but with confluent junctions,

Fig. 11.



Section of Sewer adopted by the Croton Aqueduct Department.

having radii suitable to the peculiar circumstances of each locality. Receiving basins for the road detritus, with trapped culverts for passing the surplus water into the sewer, were fixed at the corners of the streets, or in other suitable positions. These receiving basins were from time to time cleared out by manual labour. In most cases there was a good natural fall. Each length of sewer was laid down from end to end, on an uniform gradient. In almost all instances it was found, that these arrangements were sufficient to keep the sewers free from any permanent deposit.

As regarded the example which had been adduced, of a sewer constructed with a dead level bottom, Mr. Curtis considered generally, that such a mode of construction was objectionable, on account of its decreasing the hydraulic mean depth at the outfall, where it was most needed. In most similar cases an easy gradient would be preferable, as affording a greater sectional area at the outlet for the passage of the sewage, or the flood waters, and as occasioning less danger of regurgitation. He did not think the question of priority of invention could be entertained, in reference to the mechanical cleansing of sewers, inasmuch as similar systems had been used for cleansing out the supply and discharge sluices of the tanks in India, probably for the last thousand years.

Mr. LOVEGROVE said, what appeared to be the most remarkable circumstance about the two Papers was, that in one case brick sewers seemed to have been mainly adopted, whilst in the other tubular drains, or pipes, had been more largely employed; but as no drainage areas had been given, the relative merits of the two systems could not be compared. At Dundee, the sewerage had been laid out, so as to avoid the necessity of purchasing water from a public Company. To accomplish this, the sewers had been constructed at such relative depths, as to admit of the sewage being turned from one channel into another, and this, doubtless, caused the gradients to be kept as low as 1 in 600 and 1 in 700, which would favour a deposition of silt. Then there was the expense of shafts at every forty yards, and the application of mechanical arrangements for the purpose of cleansing. It was a question, whether it would not have been better and more economical, to have paid the Water Company for a proper supply of water, and have depended upon that for the scouring power, rather than to have reduced the gradients sufficiently to enable the water to be turned from one channel to another. With a series of sewers constructed on rising ground at different levels, it was easy to intercept the sewage at various points, and to make use of the several sewage currents as a scouring power. If, however, the land was level, and the sewers were about the same relative vertical height, the intercepting sewers must be nearly on a dead level, thus reducing the scouring power of the system to a minimum. He thought, that if a greater fall had been given to the sewers at Dundee, and an occasional supply of water had been obtained from the Water Company, the expense would have been less than that incurred in the original construction on this plan. There must be nearly a thousand shafts, solely for the purpose of removing the deposit, and their cost could not be calculated at less than £5,000 or £6,000; added to which the expense of manual labour would have been decreased by 50 or 60 per cent. if the other plan had been adopted. The form of street-gully was also objectionable, as it would allow of large quantities of road detritus entering the sewers. The cess-pit below the grating was about 10 inches in depth, and would contain about one cubic foot. When the cess-pit was filled, and while water passed through the hanging flap-valve, the sediment would escape into the sewer. Such a cess-pit, he thought, was not large enough for protection against the intrusion of road detritus. There were certain principles which should be observed in the construction of gullies. They should be so made as to prevent road detritus from entering the sewers, and to arrest the escape of noxious effluvia, while at the same time they should provide for the admission of a downward current of air, to aid in the ventilation of the sewer. With untrapped and imperfect gullies this downward current existed, but they also permitted the foul air to escape through the same channel. The gullies in Preston were an instance of this, as unless there was a sufficient quantity of water there could be no trap, for as soon as the water was evaporated below the syphon dip, the gully was no longer trapped, and the sewer was in direct communication with the outer air. The same state of things existed in Derby and in Leicester. He had noticed many instances, in those towns, where the water had evaporated below the syphon dip, and where a direct current of foul air escaped from the sewers, through those defective gullies. In many cases these gullies were placed within two, or three yards of the windows and doors of the dwelling-houses. With reference to the direction of the air passing through sewers, it had been asserted, in the course of the discussion, that the more powerful the current of water passing along a sewer, the more powerful would be the current of air in the contrary direction; while in one of the blue books issued by the General Board of Health, it was stated, that there was always a flow of air in the direction of the sewage current. He had tried some experiments as to the direction and temperature of the air in sewers, but he had not found any relation between the flow of the water and the direction of the air. The latter was sometimes with, and sometimes against, the sewage flow, and did not appear to be governed either by the velocity, the temperature, or the direction of the sewage; but to be determined by the various points of ingress and egress, and by the number of gullies and ventilating shafts.

Mr. Lovegrove then directed attention to a model of a vertical inspection shaft designed to facilitate the cleansing and ventilation of small sewers, and described its principal effects with regard to ventilation. Also a form of gully trap combining the three principles before adverted to; to prevent the escape of noxious effluvia from the sewers, to protect the sewers from the entrance of road detritus, and to aid in the ventilation of the sewers, by providing for the admission of air, as a downward current. These subjects he proposed to bring more prominently before the Institution on a future occasion.

Mr. WILLIAMS said, in reply upon the discussion, the principal objection to the Newport works had been, that he had carried brick sewers too far, and that a saving would have been effected by using pipes. He thought by referring to the prices given on Plate 4, it would be seen, that there would have been little saving by adopting pipe drains in any part. The smallest brick sewers, 14 inches in diameter, were built at a depth of 10 feet, at a cost of 7*s.* 7*d.* per lineal yard, including the junction pipes for the house drains; and according to his estimate and experience a pipe drain 12 inches in diameter would have cost that sum, or rather more. The only other prices that had been given, were those relating to the works at Dundee, where the average cost was—brick sewers 33*s.*, and tubular drains 13*s.* per lineal yard; whilst he had constructed sewers large enough for a man to traverse at 11*s.* per lineal yard, and these with radiating bricks, specially made for the purpose, samples of which were shown. He thought that a sewer of those dimensions would be preferred to a pipe drain, through which a man could not pass.

With regard to what had been said, as to the rate of mortality, he might state, that the average of several years before 1850 was 30·3 per 1,000. He had taken the figures very carefully from the returns of the registrar of Newport, inasmuch as at the time he had no opportunity of obtaining the Registrar-General's Report; and probably there was some difference in the boundaries of the districts over which the averages had been taken. But, in confirmation, he read a letter from Mr. W. Downing Evans, the Registrar of Newport, dated the 13th of February, 1863, which said, "the number of deaths I registered last quarter was 128, chiefly from diseases of the respiratory organs; there was not one case of fever. The mortality of Newport became much reduced immediately upon the formation of the drainage, and I estimate it to be now 22 per 1,000."

Further, in the Report, for the last three months of 1862, of Dr. Davies, the Medical Officer of Health for the borough, it was said, "not one death has been recorded from continued fever, which is a most remarkable immunity among so large a population, and is, no doubt, chiefly to be attributed to our excellent and thorough system of drainage."

Mr. HAWKSHAW, President, concurred in the opinions which had been expressed, as to the necessity for the thorough ventilation of sewers. The fact seemed to be overlooked, that a sewer was an inverted receiver, and could not with safety be hermetically sealed. If the gases were not allowed to go out into the streets, they must pass into the houses. Those who constructed sewers should be bound to provide frequent inlets and outlets, at given distances. He believed the best way to render sewer gases innocuous was by a large admixture of atmospheric air. He agreed, that not only must the gases be let out, but air should also be admitted into sewers; he did not, however, quite concur in the suggestion as to charcoal filters, through which gases had to escape, not because he did not wish the gases to be purified, but because in proportion to the extent to which that plan was adopted, would the ingress of atmospheric air into the sewer be obstructed. He believed, that if the sewers of London had ventilating shafts at every 100 yards, by which air could have entrance and exit, the metropolis would be in a much better and healthier state; and when he heard of sewers being constructed wholly without ventilation, he felt thankful he did not live where such plans were adopted. With reference to the sample of earthenware invert for sewers, having at one time filled the office of a Metropolitan Commissioner of Sewers, he had paid some attention to the subject, and he believed that this plan of invert was a mistake. It was well known, that the bottoms of the sewers were subject to the greatest wear, and the inverts, to which he referred, had a thickness of only an inch. It was along the invert that the grit and other triturating matters passed, and it formed the pathway for the men, who used their shovels upon it, when cleansing the sewers, and an invert, only one inch in thickness, was the weakest and worst thing that could be applied.

With regard to the fouling of rivers, no doubt by vastly increasing the local burdens upon trade and manufacture, means might be provided for depositing the heavy matters, and for deodorising and disinfecting the fluid portions of sewage; but such nuisances were, to some extent, the penalty incurred for concentrating the population in dense masses, and it was hopeless to expect, that the rivers in the neighbourhood of large manufacturing towns could ever be restored to their former state of purity.

February 17, 1863.

JOHN HAWKSHAW, President,
in the Chair.

The discussion upon the Papers No. 1,053, "On the Drainage of Dundee," by Mr. Fulton, and No. 1,054, "On the Sewerage of Newport," by Mr. A. Williams, was continued throughout the evening, to the exclusion of any other subject.

February 24, 1863.

JOHN HAWKSHAW, President,
in the Chair.

No. 1,063.—"American Timber Bridges." By JAMES ROBERT MOSSE, M. Inst. C.E.

IN presenting the following description of American Timber Bridges, the Author desires to direct attention to some designs, which, though they may afford only feeble interest to Engineers in England, are practically the only works available in new and comparatively poor countries, where the cost of more permanent structures cannot be supported, but where timber is abundant and cheap.

The magnitude of the rivers in the United States early required extensive bridges, even for the common roads. Viaducts of considerable length, in spans of from 150 feet to 200 feet, are often met with, although the financial means of the country had always an inverse ratio to the work to be performed. Hence structures of timber are more frequent than those of iron, or stone; and the expense of skilled labour in America has still further necessitated the erection of cheap and expeditious works. Indeed, considering all the circumstances of the early struggles, the rapid growth of the country, the past state of the finances, and the value of money, always worth at least 6 per cent. per annum, it was evident economy to erect a bridge, costing, say £5,000, even if it had to be rebuilt in twelve, or fifteen years, rather than to construct one at an expenditure of £10,000, which would not require renewal.

In the order of introduction, the first design to be noticed is the

Lattice Bridge. The earlier common road bridges, for spans of 100 feet and upwards, were generally built on the lattice plan. The sides and the top and bottom chords were formed of planks, usually 12 inches wide by 3 inches thick, fastened together by oak trenails 2 inches in diameter. For road traffic, with moderate spans, this bridge answered tolerably well; and several of the earlier railway bridges were thus constructed. But the lattice design, having proved insufficient for heavy trains, has long since been abandoned. Heavy railway traffic has shown "that, owing to the great number of joints, the shrinking of the timber in seasoning, and the absence of any heavy continuous piece of timber, distributing the strains of passing trains over the whole bridge, and then on to the abutments, the settlement of these lattice bridges was certain and rapid, so much so as, in some instances, to assimilate to a wooden suspension-bridge. The joints of the chords tear asunder below, the lattice pieces split, and the top buckles until the bridge becomes unsafe, or impassable." To maintain these bridges, it has always been found necessary to add some new element of strength, frequently in the form of a queen-post truss, but more usually by the addition of arched ribs, on each side, without which many American engineers consider "no railway timber bridge safe, or efficient." They state also, that the arch has "answered admirably, wherever used either to strengthen a failing bridge, or as embodying the main principle of strength in a new one." Attention has thus been drawn to the defects of the lattice plan, because it has been erroneously supposed in England, to be the usual style of American bridges.

After one, or two other designs, which need not be particularly mentioned, the Howe Bridge (Plate 6, Fig. 1) became extensively used for railways in the United States. The earlier bridges of this class were usually from 100 feet to 150 feet span; but arches are now generally added, when they approach, or exceed the latter dimension. For spans of 100 feet this design stands well. It is light, cheap, and very simple in construction. The ordinary price for a single line, including erection, is from £4 to £5 per lineal foot; and for spans of 150 feet, with arches, from £5 to £6 per lineal foot.

The Howe bridge was the first design in which any camber could be easily given by means of the tie-rods; and counter-braces were introduced, by which, when keyed up, the bridge could be so stiffened, that a passing load was said to produce no additional strain upon it. Especial care was also taken in forming the bottom chords, so as to resist, as much as possible, the tensile strain. As now constructed the panels are generally from 10 feet to 11 feet wide, and the bottom chords, four in number on each side, are from 40 feet to 44 feet long, and 6 inches by 12 inches in section. The bottom chords thus extend over four panels; and they are so arranged, that there shall be only one joint in the chord pieces, in any one panel. Oak splicing-pieces, 6 feet long, are inserted at every joint, and oak keys, 12 inches long by 2½ inches wide, are let in ¾ inch between each chord piece, at intervals of 5 feet; and the whole of the chords are bolted together by numerous bolts, in order to keep them from stretching. There has always been difficulty in preventing the extension of the bottom chord, and in rendering the bridge rigid. The former is obviated by the manner in which the chord is made solid by the oak keys and bolts; and the latter is obtained by keying up the counter-braces, so as to prevent the undulations which the trains would otherwise cause. The main braces increase from the centre to the abutments; but they are sometimes found insufficient for the strains coming on them in the first and second panels. The angle blocks at the top and bottom of the braces are sometimes of oak, but generally of cast iron. The vertical rods, usually three in number in each panel, but sometimes only two, vary from 1¾ inch diameter at the abutments to 1¼ inch diameter at the centre. The joists, 6 inches by 12 inches in section, rest on the bottom chords, at distances of 2 feet 9 inches from centre to centre; and upon these are placed the longitudinal pieces, which carry the rails.

Plate 6, Fig. 1, is an ordinary Howe bridge of 121 feet span, built over the James River, at Richmond, on the line of the Danville Railway. The principal dimensions of this bridge are—Length, about 1,800 feet; general span, 121 feet; number of trusses, 2; number of spans, 11; width of panel, 11 feet; total depth of truss, 20 feet; and width of bridge outside, 18 feet.

The upper chords consist of two pieces 9 inches by 12 inches, and four pieces 5 inches by 9 inches, having a total sectional area of 396 square inches. The bottom chords consist of four pieces 6 inches by 12 inches, and four pieces of 5 inches by 12 inches, having a sectional area of 528 square inches. The area of the bottom chord is always greater than that of the upper chord, on account of the numerous joints in the former. The end main braces—eight in number, four at each end of the bridge—are 8 inches by 9 inches, giving a sectional area of 576 square inches. The counter-braces are 7½ inches by 7 inches; the tie-rods at the abutments are 1⅝ inch diameter, and have a sectional area of 2 square inches, while those at the centre of the bridge are 1½ inch diameter, with an area of 1¾ square inch.

These bridges are always built of the best white pine. The usual quantity of timber in them is about 30 cubic feet per lineal foot. This, at 35 lbs. per cubic foot, is equal to 1,050 lbs., and, adding for ironwork 120 lbs., gives the total weight as about 1,170 lbs., or little more than half a ton, per lineal foot. Assuming a load of 2,000 lbs. per lineal foot to be uniformly distributed over this bridge, or say 3,000 lbs., including its own weight, then, by the ordinary calculation,[1] the strains are—

On the upper chords,	compression,	729	lbs.	per square inch.
„ bottom chords,	tension,	547	„	„
„ end braces,	compression,	735	„	„
„ end tie-rods,	tension,	15,125	„	„

It may be interesting to give the ordinary dimensions for a span of 150 feet, built without arches, on the Portland Railway. Span in the clear, 150 feet; whole length of chords, 164 feet; number of trusses, 2, each 19 feet in height; and number of panels, 14, each 10 feet 9 inches long. The width of the bridge between the trusses, if the rails are placed on the top of the bridge, is 12 feet; and if on the bottom chord, 14 feet. Two of the lower chord pieces are 6 inches by 13 inches, and the other two are 7 inches by 13 inches, with a total sectional area of 676 square inches for both sides. The whole of the lower chord, when packed, measures 13 inches in depth by 30 inches in width. Two of the upper chord pieces are 6 inches by 10 inches, and the other two are 7 inches by 10 inches, with a total sectional area of 520 square inches for both sides. The whole of the upper chord, when packed, measures 10 inches in depth by 30 inches in width. The main braces, for three panels from the abutments, are $8\frac{1}{2}$ inches by $10\frac{1}{2}$ inches, the rest of the main braces being 8 inches by $10\frac{1}{2}$ inches. The counter-braces are 7 inches by 9 inches. The main tie-rods are $1\frac{5}{8}$ inch diameter; three panels from the abutments having three rods each, and the other panels two rods each. The diagonal braces are 6 inches by 7 inches, and the bolts through these diagonals are $1\frac{1}{4}$ inch diameter. The splicing bolts through the chord pieces are always $\frac{3}{4}$ inch diameter.

Assuming the same weight, 3,000 lbs. per lineal foot, to be equally distributed over this structure, the strains are—

On the upper chord,	compression,	901	lbs.	per square inch.
„ bottom chord,	tension,	694	„	„
„ end main braces,	compression,	750	„	„
„ end tie-rods,	tension,	18,750	„	„

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[1] In the case of the upper chord,

$$\frac{121 \times 3{,}000 \text{ lbs.} \times 121}{396 \text{ (area) } \times 8 \times 19} = 729 \text{ lbs. per square inch.}$$

In that of the bottom chord,

$$\frac{121 \times 3{,}000 \text{ lbs.} \times 121}{528 \text{ (area) } \times 8 \times 19} = 547 \text{ lbs. ,, ,,}$$

The strain on the last main brace is,

$$\frac{121 \times 3{,}000 \text{ lbs.} \times 21 \text{ feet diagonal}}{8 \text{ braces} \times 8 \text{ in.} \times 9 \text{ in.} \times 18 \text{ feet height}} = 735 \text{ lbs. ,, ,,}$$

The strain on the end tie-rods is,

$$\frac{121 \times 3{,}000 \text{ lbs.}}{12 \text{ (No.) } \times 2 \text{ inches area}} = 15{,}125 \text{ lbs. ,, ,,}$$

It will be observed, that in this case the strains are considerably greater than in the first example, of 121 feet span, and that the compression of 901 lbs. per square inch on the upper chord reaches the limit of a safe strain. It is not likely, however, that this bridge will ever be loaded to the amount assumed. At the same time it should be remembered, that the pressures above mentioned are those resulting only from. the dead weight, and that they do not include the strains caused by the concussion of trains.

It will be evident from what has been stated, that for the increased weight of trains and the enlarged span of railway bridges, it was afterwards found necessary to strengthen the Howe Bridge, by arches on each side of the truss. This IMPROVED HOWE TRUSS, as it is called, for several years came into general use. Plate 6, Fig. 2, gives one of the best examples of this bridge, built for a double line on the Philadelphia and Reading Railway, where it is subject to the heaviest traffic in America. The principal dimensions are, span 160 feet in the clear. The trusses are three in number, and 23 feet deep; the upper chords are composed of four pieces, each 15 inches deep, and together 27 inches in width. The bottom chords are also of four pieces, each 20 inches deep by 27 inches in total width, keyed and bolted together in the manner described in the first example. The sectional area of the upper chords is, therefore, $3 \times 15'' \times 27'' = 1{,}215$ square inches, and that of the bottom chords is $3 \times 20'' \times 27'' = 1{,}620$ square inches. The arches, six in number, one on each side of each truss, are formed of the best pine, in pieces about 24 feet long by $4\frac{1}{4}$ inches wide and 15 inches deep. There are four such pieces in each arch, making together $8\frac{1}{2}$ inches wide by 30 inches deep, and giving a sectional area of 255 square inches. These pieces are made to break joint at every 6 feet. Timber arches have not unfrequently been built of pieces 6 inches square; but they are very rarely constructed of laminated 3-inch planks in the manner formerly practised in England. The thicker pieces are found to be a convenient size, and are considered preferable, as there are fewer joints by which water can penetrate. Care is always taken that they break joint in the most approved method. The sectional area of the arches is, therefore, $6 \times 8\frac{1}{2}'' \times 30'' = 1{,}530$ square inches. The main braces are 8 inches by 10 inches; the counter-braces being 8 inches by 8 inches. The width of each panel is about 10 feet 3 inches, and the vertical tie-rods are $1\frac{5}{8}$ inch diameter.

Referring to this bridge, Mr. G. A. Nicolls, the Chief Engineer of the Railway, states that "it is composed of a combination of the Howe truss and arch, and is susceptible of having the strain borne by each, either exactly equalised, or as much thrown upon either truss as may be desirable. . . . No other combination of bridge possesses the strength and efficiency of this plan. We have had loaded coal-waggons, which got off the rails on a grade above this bridge, in a train weighing 700 tons, brought up, all standing, inside the bridge after knocking out, or breaking, several of the main braces of the Howe truss, thus leaving the whole bridge and train suspended by, and depending upon, the arch alone, while trains were passing on the other line of rails."

As before remarked, this bridge affords an excellent example of a timber structure subject to very heavy loads; for the coal traffic which passes over it is unusually large, amounting to fully 1¾ million tons per annum, or more than 5,000 tons daily, besides the ordinary passenger and goods trains.

It appears, by calculation, that the strength of this bridge is considerably in excess of what may be deemed necessary. For, supposing the bridge to be covered on both lines with locomotives, or say 3 tons per lineal foot equally distributed, including the weight of the structure itself, then if the load be borne equally by the upper chords and the arches, the compressive strain on the former is 292 lbs., and on the latter 237 lbs. per square inch; and supposing the load to be sustained by the arches alone, the pressure, even then, only amounts to 468 lbs. per square inch, while practically the bridge is never likely to be loaded to this extent. About 900 lbs. per square inch is usually considered by American Engineers to be the limit of safe compression on timber framing.

The following are approximate quantities of the materials in this bridge, exclusive of the roof. Timber 10,554 cubic feet; wrought iron 22 tons, and cast iron 7 tons; or, per lineal foot of bridge, 58 cubic feet of timber, 270 lbs. of wrought iron, and 76 lbs. of cast iron: the total weight being a little over one ton per lineal foot. The cost of this bridge, for a double line, with three trusses, "exclusive of the masonry and roof, but including all materials, timber, iron, castings, kyanizing, mechanical work and erection, while the full business of the railway was passing at the same time, amounted to £1,868, or £10. 3*s.* per lineal foot. Under ordinary circumstances it is believed the bridge could have been put up for £100 less, as the passage of numerous trains interfered greatly with the workmen."

These bridges are usually built with about 12 inches of camber, and as regards deflection, Mr. Nicolls states "that a well-built timber bridge in America would not settle more than ½ or ⅝ inch under a heavy engine and train;" and that "on the Philadelphia and Reading Railway one of these bridges settles only ¼ inch under an engine of 28 tons hauling a train weighing 0·64 ton per lineal foot." The Author presumes this deflection was measured shortly after the bridge had been erected; for heavy trains, and the decay of the timber at the joints, tell upon these structures so much, that they soon deflect, and do not last in good condition more than from twelve to fifteen years. This heavy wear and tear results, in a great measure, from the unseasoned state of the timber when it is framed. It is generally very difficult to get seasoned timber anywhere in America, and much more so on a railway; and timber put into framing green from the woods, say within two, or three months after being cut, cannot be expected to stand. To obviate the effects of the shrinkage, which will necessarily take place, much greater care and attention are requisite, than are generally bestowed; so that these causes combined, readily account for the short duration of timber bridges. It is the custom to cover these structures with a roof, and to close in the sides with boarding 1 inch thick; and when thus protected from the weather and cared for—any shrinkage of the braces being immediately remedied—it is believed these bridges will remain in good condition double the usual time, or about twenty-five years.

There are, on the other hand, Engineers in the United States, who do not approve of the arch in combination with the truss. They hold that a structure composed of two systems, neither of which is strong enough by itself, is defective in principle, and they state it to be very difficult, if not impossible, so to proportion the weight upon each system, as to make each bear its proper share. Practically the best mode of obtaining this combined action, seems to be, the removal of the scaffolding before the suspension-rods from the arches are secured to the joists, and then by tightening these rods to make the truss rise slightly. These Engineers are of opinion, that the better plan is to follow one system; either to place in the truss the material used in the arch, thus making the truss sufficiently strong by itself, or to depend entirely upon the arch, and use a light truss merely to stiffen the roadway. There is also a minor objection to the combination, viz. that in a climate varying 150° in temperature, the rods which suspend the roadway from the arch, being of unequal lengths, will expand and contract considerably and unequally, and thus give much trouble in keeping them somewhat, not to say uniformly, adjusted. The arched bridge has likewise the disadvantage of requiring the piers to contain at least twice the quantity of masonry which would be sufficient for a truss bridge, having no horizontal thrust.

The piers of American truss bridges are generally well built, of solid granite ashlar masonry, but they are remarkably slight. When from 60 feet to 80 feet in height, the piers are usually 5 feet thick at the top, but many are only 4 feet thick. They are generally built with a batter of ½ inch to the foot at the sides, and ordinarily stand well. Granite being abundant in all the Eastern States, brick piers are comparatively rarely built. On a railway in Virginia, on which the Author was engaged, a viaduct 2,000 feet in length and averaging 80 feet in height, was carried on brick piers of the following dimensions, built hollow, and not filled with concrete, but having a centre cross wall:—Height 80 feet, width of the pier at the bottom 26 feet 8 inches, and at the top 20 feet. The external breadth at the bottom was 13 feet 8 inches, and at the top 7 feet. The thickness of the walls at the bottom was, two walls each 3 feet 4 inches, making 6 feet 8 inches, and at the top, two walls each 2 feet 4 inches, making 4 feet 8 inches. For 8 feet below the top of the pier, the brickwork was solid, so as to receive and distribute the concussion caused by the trains. These piers are said to have stood satisfactorily.

With reference to the great height of some timber piers, it may be interesting to mention, that on the Buffalo and New York Railway, a truss bridge has been erected across the Genesee River, supported on trestles of timber framing 190 feet high, the total height from the bed of the river to the rails being 234 feet. This viaduct is 800 feet long, and has nine piers each about 190 feet in height. It was commenced in July 1851, and was finished in August 1852. It is still in use, and has never failed in any particular, except by the natural decay of the timber, which is so framed without mortices, or tenons, that any decayed pieces can be easily replaced. This work contains,—timber 133,500 cubic feet; ironwork, bolts, &c. 108,862 lbs.; masonry in cement, 9,200 cubic yards.

Timber-bridge building has become an especial branch of Engineering in the United States, and there are several firms who devote their whole time to this subject. The large number of bridges required for 30,000 miles of railway has necessarily given great field for experience, and many designs having been tried, the plan of bridge now the most general, becomes of course the more valuable. Of the firms alluded to, one of the most eminent is that of Mr. D. C. McCallum, an Engineer of high standing, who was for several years the manager of the New York and Erie Railway, a length of 460 miles, exclusive of branches. The INFLEXIBLE ARCHED TRUSS being now probably in more general use than any other bridge, Mr. McCallum has, at the request of the Author, furnished the plans shown in Plate 6, Figs. 3 and 4. The Author would remark, in passing, that he believes the first mention of this bridge, and of Mr. McCallum's admirable system of working trains by the electric telegraph, will be found in Captain Galton's Report on the Railways of the United States.[1]

Plate 6, Fig. 3, is a railway bridge, for a single line, 200 feet span; several of which have been erected in the States of New

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[1] *Vide* "Report on the Railways of the United States." By Captain Douglas Galton, R.E. Folio. London. 1857.

York, Ohio, and Mississippi. The principal dimensions are: length, 210 feet; span, 200 feet; depth of the truss in the centre, 26 feet, and at the ends, 21 feet. The arched top has two pieces, 7 inches by 11 inches, one piece 16 inches by 11 inches, and one piece, 7 inches by 11 inches, together giving a sectional area of 407 square inches, or for both sides, of 814 square inches. The bottom chord is composed of four pieces, each 7 inches by 14 inches, but which only afford an available clear sectional area, excluding notches and scarfs, of 234 square inches, or 468 square inches for both sides. The main braces, which project 32 feet from the pier, are each 11 inches by 16 inches, and give a sectional area of 704 square inches on each side. The posts, of which there is a double row, inserted between the chords, vary from 9 inches by 13 inches at the abutments to 9 inches by 6 inches at the centre. The counter-braces are 9 inches by 6 inches throughout.

It is desired to direct special attention to the manner in which the bottom chords are scarfed, by long splicing pieces and by combination keys, let 1 inch into each chord, at every 4 feet, or 5 feet, and by numerous bolts, so as to prevent them, as much as possible, from stretching. It will also be noticed, that the spur-arch braces transfer the load directly on to the abutments; therefore the braces at the ends of the bridge are relieved from a large portion of the strain which would otherwise fall upon them, and the span becomes practically reduced, so far as the strain on the truss is concerned, to 136 feet. This bridge contains 7,360 cubic feet of timber, 6,958 lbs. of wrought iron, and 5,997 lbs. of cast iron. It cost, including erection and every expense, £5. 4*s*. per lineal foot; the rough timber being taken at one shilling per cubic foot, delivered on the site of the work. The total weight, including the permanent way, is 109 tons. When loaded with 205 tons in addition, or say 314 tons equally distributed, the pressure on the arched top will be 862 lbs. per square inch, and the tension on the bottom chords will amount to 1,500 lbs. per square inch.

Mr. McCallum has informed the Author, that this bridge, when loaded with locomotives and tenders, the whole weighing 195 tons, "or very nearly one ton per lineal foot, deflected about $\frac{3}{4}$ of an inch previous to any adjustment of the counter-braces; that while the load was upon the bridge, the counter-braces were screwed down, and when the load was removed, the structure rose slightly, due to the compression of the counter-braces, but leaving a permanent deflection caused by their action of nearly $\frac{5}{8}$ of an inch." In the calculation as to strains, "the strength has been considered as a truss simply, without taking into account the arch brace system, which of itself is sufficient to sustain both the bridge and the load."

As bearing on this point, Mr. Gardner, the Superintendent of Bridges on the Ohio and Mississippi Railway, states that "on the

12th of March, 1858, an engine was thrown off the rails 100 yards distant from a McCallum bridge of 94 feet span. The train was running at high speed, and before it could be stopped, the engine had reached the centre of the bridge with all its wheels off the rails, and upon it were piled, one baggage van and two passenger carriages. The concussion broke the lower chords of both trusses of the bridge, together with six posts, twelve braces, and thirty floor beams. The engine, after having passed through the floor timbers, was arrested in its course by coming in contact with the longitudinal rail pieces and the lateral rods. The lower chords being broken, the whole train was prevented from falling into the stream, by the sustaining power of the arch and arch braces alone."

It will be remembered that a similar accident, exhibiting the strength of the arch, has been previously mentioned respecting the Improved Howe Truss,[1] which formed the last example; and that the deflections of both these bridges were not only very slight, but were nearly identical.

In Appleton's 'Mechanics' Magazine and Engineers' Journal,' 1st April, 1852,[2] it is stated that, on the 29th January of that year, a McCallum bridge, 190 feet span, built over the Susquehanna River, was tested by a number of engineers and bridge-builders, by running from one to four locomotive engines and tenders over it at different rates of speeds. "Upon placing, first, one engine and tender upon the centre of the bridge, and noting the deflection; then bringing on successively the second, third, and fourth, and arranging them as near the centre of the bridge as possible, the deflections were found to be as follows:—

	Gross Weight.	Deflection in Feet.
One engine and tender . .	37 tons	0·02
Two " " . .	85 "	0·04
Three " " . .	125 "	0·06
Four " " . .	167 "	0·06

"On removing these engines from the bridge, it was found that the truss had entirely resumed its original level, showing that the elasticity of the timbers was unimpaired." Referring to this bridge, Mr. Post, Chief Engineer of the New York and Erie Railroad, stated, in a letter dated May 15th, 1858,[3] that it had "been in use nearly seven years, without having cost one cent for watchmen, adjustment, or repairs, except a coat of paint last year, and is now in perfect condition." Mr. Post also states, that there are on that railway one hundred McCallum bridges, on the aggregate nearly 3 miles in length, subject to passenger trains of 100 tons, at speeds of from 25 to 50 miles per hour; that the average weight of the goods trains passing over these bridges is 262 tons, at speeds of from 15 to 20 miles per hour; and that there are about ten trains of each class daily, besides those employed in ballasting, moving wood, and the other supplies of the railway. As regards the durability and economy of these bridges, Mr. Post speaks of them in the highest terms, preferring them to "any other in use for railroad purposes."

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[1] *Vide ante*, p. 309.

[2] *Vide* "McCallum's Inflexible Arched Trust Bridge." Explained and Illustrated. By D. McCallum. Tract 8vo. Plate and Cuts. New York. 1859. Page 41 *et seq.*

[3] *Ibid.* p. 46.

The Author is informed by Mr. McCallum, that "there are at present nearly 15 miles in length of these bridges upon different railways, in spans varying from 30 feet to 260 feet in the clear, and in no case have they been so unfortunate as to have a failure." The spans of 260 feet here referred to, the largest yet constructed on this principle, are those built on the New York and Erie Railway, over the Delaware River; but Mr. McCallum expressed to the Author, a few months back, his entire confidence in erecting similar spans of 300 feet in the clear.

Plate 6, Fig. 4, is a design for a railway swing bridge, having two openings of 150 feet each, to be erected over the Mississippi River at Clinton, in Ohio. Several railway swing bridges, with spans of 120 feet each, have been already constructed on a similar plan, with complete success; and although, owing to the present condition of America, the particular bridge in question has not yet been erected, Mr. McCallum, from previous experience, has perfect confidence in its feasibility. The principal dimensions are—length, 335 feet; length over turntable, 30 feet, and diameter of turntable, 29 feet; clear span of each opening, 150 feet; depth of the truss at the centre 34 feet, and at the ends 10 feet. The arched top is composed of four pieces, each 6½ inches by 10 inches, giving a sectional area of 260 square inches on each side. There are also three pieces of straining beams, about 8 inches square, which extend in different lengths from the centre towards the ends, to strengthen the top when the bridge is open. The principal spur braces, 8 inches by 14 inches, extend on both sides, about 80 feet from the turntable. It will also be noticed, that in addition to the ordinary posts and diagonals, this system of spur bracing pervades the whole structure. The bottom chord is formed of four pieces, each 6½ inches by 12 inches, scarfed and stiffened by combination keys and numerous bolts, the sectional area being 312 square inches on each side. The quantity of timber in this bridge is about 12,600 cubic feet, of wrought iron, 18,973 lbs.; and of cast iron, 17,845 lbs. The total weight may be taken at 200 tons, or, not including the central portion, 90 tons for each span. If to this weight a load of

1 ton per lineal foot be added, making 240 tons equally distributed over each opening, the strains will be—

On the arched top, compression,	808 lbs.	per square inch.
On the lower chord, tension,	1,077 lbs.	„

When the bridge is swinging open, there will be,—

On the arched top, tension,	1,218 lbs.	per square inch.
On the lower chord, compression,	609 lbs.	„

In the above and previous calculations respecting the bridge shown in Fig. 3, which are quite independent of the spur brace system, the tension has been taken on the available sectional area of the bottom chord; in other words, usually on the area of three of the chord pieces instead of four, as one of these pieces having a joint in every panel is seldom included in such estimates. If the spur braces should take the whole of the weight of this bridge when open, they would be subject to a strain of from 600 lbs. to 700 lbs. per square inch. In order to prevent any sinking of this bridge at the ends, the truss can be adjusted by means of the counter-braces, and provision is also made to bring the spur braces into action, so as to obviate that tendency. The bridge swings on a turntable 29 feet in diameter, and it is said will require only two men to turn it. The cost of this structure, including the turntable and erection, will be about £10 per lineal foot.

With reference to the deflection of railway timber bridges after several years' use, Mr. McCallum informs the Author that, "the earlier bridges were constructed of timber in every condition, from perfectly green, or wet to nearly seasoned; that spans from 150 to 200 feet were cambered in the chord from 6 inches to 10 inches according to the state of the timber; and that very few, if any, of the bridges have deflected below a straight line."

Plate 6, Fig. 5, is a McCallum common road bridge of 150 feet span,—a dimension in more general use than any other. This design is similar in principle to that shown in Fig. 3, though built with only a single row of posts, and with timbers of light scantling. The following are its principal dimensions, length, 155 feet; span, 150 feet; width in the clear, 20 feet; depth of the truss at the centre, 20 feet 6 inches, and at the ends, 16 feet 6 inches. The arched top is composed of two pieces 7 inches by 10 inches, and of two pieces, 6 inches by 8 inches, giving a sectional area of 236 square inches. In the bottom chord, there are two pieces 7 inches by 12 inches, making a sectional area of 168 square inches on each side. The braces are 8 inches by 10 inches at the abutments, and 6 inches by 10 inches in the centre. Taking the weight and load of this bridge to amount to 1 ton per lineal foot, the strains will be, on the arched top, with a sectional area of 472 square inches, 685 lbs. per square inch;

on the bottom chord, with a sectional area of 336 square inches, 961 lbs. per square inch. The quantity of timber is 23 cubic feet per lineal foot; and the entire cost of the bridge, including erection, amounts to only £3. 2*s*. 6*d*. per lineal foot, the rough timber on the ground being estimated at ninepence per cubic foot.

Plate 6, Fig. 6, is a simple adaptation of the Howe Truss to roofs of considerable span, a very common construction in the United States. The span of this roof, erected at the Dunkirk Station of the New York and Erie Railway, is 80 feet, though similar roofs are frequently found of greater width. The top and bottom chords are formed of the following scantlings:—two pieces, each 5 inches by 7 inches, giving a sectional area of 70 square inches; and one piece 6 inches by 7 inches, with a sectional area of 42 inches, together amounting to 112 square inches. The braces diminish from 5 inches by 7 inches at the walls, to 5 inches by 4½ inches at the centre. The counter-braces, 5 inches by 3 inches, remain the same throughout. This roof is chiefly remarkable for the lightness of the scantlings, only two pieces of timber being as large as 6 inches by 7 inches, and most of them being about 5 inches by 7 inches. A principal of this roof contains 280 cubic feet, and at the ordinary price for timber framing, would cost, including erection, about £35.

In concluding this slight sketch of American Timber Bridges, the Author feels it to be unnecessary to go more into details, even if the limits of a single Paper did not preclude his doing so. He avails himself of this opportunity to record his best acknowledgments to American Engineers, for the courtesy they have invariably shown, in taking him over their works, and in affording him every information and assistance in their power.

The Author believes that these bridges have been accurately designed in proportion to the strains coming on the timbers in the several parts; but whatever may be their merits, or their faults, they have produced good practical results and will bear investigation. This Paper is presented in the hope that these specimens of timber work, the result of many years' experience, and the adaptation of the only available resources of a new and comparatively poor country, may be found interesting to the Members of the Institution of Civil Engineers.

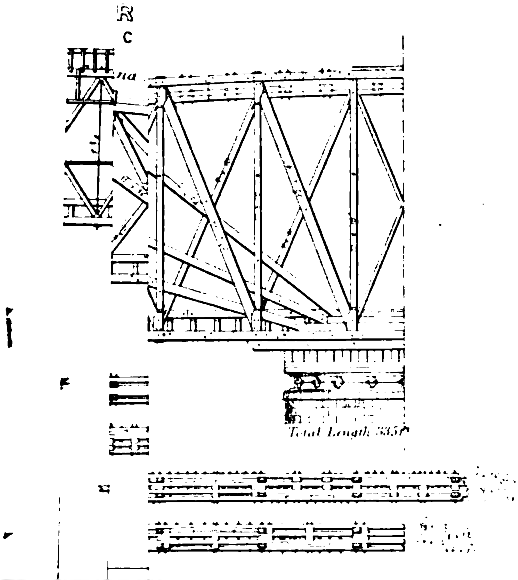
The Paper is accompanied by three drawings, from which Plate 6 has been compiled.

Mr. ZERAH COLBURN thought the Paper gave a very complete account of the construction of American Timber Bridges, but it hardly contained sufficient information to lead to a correct judgment as to the relative merits of timber and of iron. Timber had been almost exclusively used in the States, for railway bridges, chiefly because iron was beyond the means of the Railway Companies, and partly, no doubt, because its application was not so well understood. American Engineers had perhaps made a virtue of necessity, but Mr. Colburn thought there were but very few among them who would not prefer iron, or stone to the best timber bridges ever built. Whatever form of truss was employed, timber bridges were very perishable, and they were always liable to destruction by fire. The Report, for 1857, of the chief Engineer of the Pennsylvania Central Railroad, contained the following remarks:—

"The bridges have all undergone a thorough examination, and many of them found to be much decayed. This examination leads to the conclusion, that about nine years is as much as can be calculated upon for the duration of an uncovered wooden superstructure; and when the liability to fire and the expense of watching are taken into consideration, shows most conclusively that economy, as well as safety, is in favour of iron structures."

The following classification of bridges was given by Mr. Post, formerly chief Engineer of the New York and Erie Railroad, one of the most important lines in the States, in his Report on that line for 1857:—

"**A** represents bridges of the first class on this, or any other railroad. Their superstructures, composed principally of white pine, white oak, and iron, have been constructed in the most substantial manner from the best materials, and remain in every way sound and in perfect condition. When first put together, the joints were thoroughly inlaid with white lead and oil paint, and as soon afterwards as the timber became perfectly seasoned, their external surfaces were well painted, the season checks cemented, and other exposed points protected, so that the timber is almost completely secured from the effects of the weather and preserved from premature decay. If kept properly painted, these bridges will, unquestionably, with very little other repair, perform their offices well, and with perfect safety, for twenty years, or more. **B** represents bridges of the second class on this road. They were built of inferior timber, with little, or no mechanical skill, and are, generally, of too slight proportions to be of long duration. The greater number of them have been supported with 'bents' from the beds of the streams, &c., or strengthened by other expedients. They may probably be made to last, from the time they were built, about fifteen years. **C** represents bridges of the third class on this road. They are built of inferior timber, but are generally of good workmanship. Their most general defect is the weakness of their lower chords, which were not made up with strength enough to resist the tensile strain to which they have been subjected. With but a single exception, these bridges have failed, so as to require supports beneath, or to be strengthened by applying additional thickness of timber to the chords. There have been already expended, for repairs on these bridges, from five to six and a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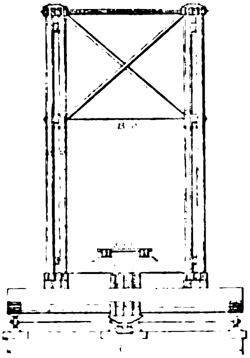

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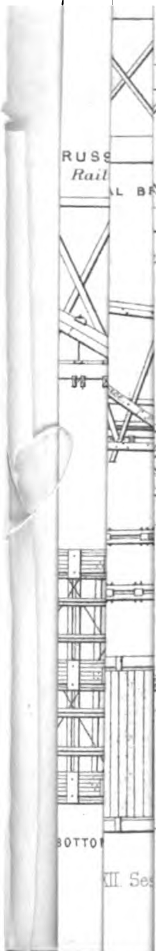
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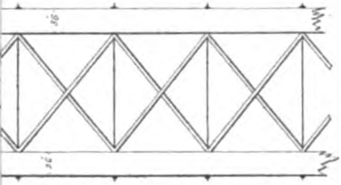
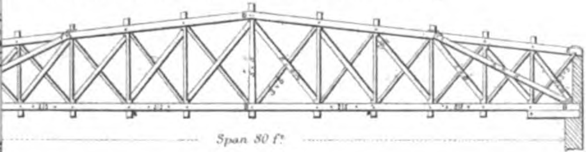


RAL BRACING.

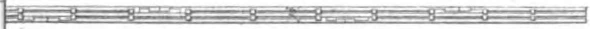
Fig. 6.

HOWE TRUSS ROOF

Dunkirk Station, New York and Erie Railway.



ELEVATION.



PLAN SHEWING BOTTOM CHORD A.B & TOP CHORD C. D. E.

KELL BROS, LITHRS CASTLE ST HOLB N.

half dollars per lineal foot, and many of them require renewal this year. The average wear will not probably exceed ten years. **E** represents bridges of the fourth class, or trestle bridges. They cost, aside from their foundation masonry, about eight dollars per lineal foot for single track, and will give about six years' service with small repairs—say at an average cost of twenty-five cents per foot per annum. Many of these have already been renewed. **D** represents bridges of the fifth class, or stringer bridges. They cost, independent of their masonry, about five dollars per lineal foot, and will last altogether about eight years. Many of them have been renewed."

Mr. Colburn stated that the New York and Erie Railroad Company was then expending £9,000 yearly in the repairs of timber bridges, exclusive of costly renewals. As an instance of what these renewals sometimes were, might be mentioned the Cascade Bridge, a timber arch of 276 feet clear span over a ravine 185 feet deep. This bridge was put up in 1848, and cost £9,000. In 1860, from fears of the failure of the bridge, the line was diverted so as to cross the stream higher up, and on an embankment over a stone culvert. The cost of this deviation was £21,000. The bridge was taken down immediately afterwards, and many of the timbers were found to be in a rotten state. Indeed timber bridges were always rotting. In 1858 a short bridge broke down under a passenger train on the New York Central Railroad, and nine passengers were killed. It was found that some of the timbers were so decayed that a walking-stick could be pushed through them. In 1860 a bridge broke down on the Albany Northern Railroad, and a number of passengers were killed. In this case, too, the timbers were much decayed. A bridge broke down about the same time on the Great Falls and Conway Railroad, in New Hampshire, and some time previously a large railroad bridge fell near Easton, Pennsylvania. One of the railway papers, the 'American Railway Times,' had a leading article, stating that there were great numbers of railway bridges just as unsound as the Great Falls Bridge and the Albany Northern Bridge. The article stated, that the editor could name ten bridges which were likely to fall in a fortnight, twenty bridges which might come down any time within six months, and forty bridges which were not safe for more than a year. Mr. Colburn could not say whether any of these bridges had yet broken down, but he had just received a copy of the 'American Railway Times,' from which he read the following extract:—

"On Monday, December 1st, the Howe Truss Bridge over the West Fork of White Lick Creek, gave way while a freight train was passing, and a portion of the train fell with it, killing a brakeman, Isaac Pratt, and a stranger, who was standing on the east abutment. The bridge had been well protected from the weather, and the timbers were all sound. Every precaution had been taken to guard against such an accident."

In very many cases American bridges were built of unseasoned timber, and they were not always painted. There was sometimes a deficiency of skill in the distribution of the material. The top and bottom chords, and also the diagonals, were often of the same scantling all the way through, even for large spans. Besides the decay of the timbers, the joints worked loose after a time, and in this way timber bridges finally became very shaky. Mr. Colburn believed this was the case with the very best forms of truss, and the inferior kinds began to go very soon. There was a large lattice bridge of nineteen spans of 153 feet each, and nearly 100 feet high, over the James River, at Richmond, Virginia. This was erected about the year 1835, and when Mr. Colburn was living in Richmond, eleven years ago, it was considered to be very weak, even for light trains crossing at a slow speed. Mr. Colburn was connected with locomotive works there, and the Railway Company objected to their heavy engines being taken over the bridge when they were being sent southwards. It was a rule, on most American railways, to cross long timber bridges at a slow speed, and on highway bridges there was almost always a notice, that a fine of five dollars would be imposed for driving a horse over faster than a walking pace.

Fires were very frequent among timber bridges. Mr. Colburn could mention a dozen within his own recollection. The White River Bridge across the Connecticut River, about twelve years ago,—the Coosa River Bridge on the Alabama and Tennessee Railroad, about eight years ago,—the Mohawk Bridge on the New York Central Railroad,—the Orwigsburg Bridge on the Reading Railroad,—the Salmon Falls Bridge on the Boston and Maine Railroad,—the Valley Creek Bridge on the Philadelphia and Columbia Railroad (the first bridge was built here in 1837, and the third was now standing on the same site),—the Lackawaxen Bridge on the New York and Erie Railroad,—the Conewago Bridge on the Lancaster and Harrisburgh Railroad (the first bridge was built here in 1837, and the fourth was now standing), besides bridges on the Pittsburgh, Fort Wayne, and Chicago Railroad, the railway bridge over the Middlesex Canal at Lowell, and others. A roadway bridge over the Schuylkill River, at Philadelphia, a single span of 340 feet, and one of the best examples of this class of construction, was also burnt.

All long bridges required watchmen, generally day and night. The Baltimore and Ohio Railroad paid £1,600 yearly for watching bridges. Large tubs of water were kept on the bridges, the water being saturated with salt, to prevent its freezing in winter. There were cases of incendiary fires. Many attempts had been made to burn the great bridge across the Mississippi River at Rock Island. The Michigan Central Railroad had several bridges burnt at one time. Since the beginning of the present war many bridges, of course, had been destroyed, and chiefly by fire.

Mr. Colburn then gave the cost of a number of American timber bridges, as follows:—The Bedford Bridge, on the Cleveland and Pittsburgh Railroad, a Howe bridge with an arch, had a clear span of 243 feet, was for a single line, and was 20 feet high: it cost 30 dollars per foot. A single line, Howe span of 230 feet, without an arch, and 24 feet high in the truss, erected, in 1853, on the Rochester and Lockport (now part of the New York Central) Railroad, cost 35 dollars per foot. A Howe bridge without an arch, of 250 feet clear span, on the Washington county road, in Texas, cost 60 dollars per foot. An arched Howe bridge over the Connecticut River at Bellows Falls, having two spans, each 250 feet in the clear and 23 feet high, cost 35 dollars per foot. The bridge over the Mississippi River at Rock Island had five spans of 250 feet each, and three spans of 150 feet. The wider spans cost 52 dollars per foot; the spans being Howe's truss, with arches, and the timbers all planed. The Miami Bridge on the Ohio and Mississippi Railroad had six spans of McCallum's truss, each 210 feet, and cost 33 dollars per foot for a single line. The Delaware Bridge on the New York and Erie Railroad had two of McCallum's spans of 262 feet each, and cost 42 dollars per foot. The Susquehanna Bridge on the same line, with 188 feet spans, cost 35 dollars per foot. The Clinton Bridge on the Galena and Chicago Railroad had seven McCallum spans of 200 feet, and cost 28 dollars per foot.

Mr. C. H. Gregory, V. P., considered that the remarks of Mr. Colburn tended to confirm the prices given by Mr. Mosse for the constructions described in the Paper. Of course the cost would vary according to the character of the work, the locality, and the convenience of transport of the timber. Mr. Mosse's opinion of the durability of these bridges was not inconsistent with what had just been stated; for the Paper no doubt alluded to bridges which had been well and carefully constructed: but when roughly executed, of inferior materials, such bridges could not be expected to be durable. The Paper would be a valuable addition to the records of the Institution, as affording instances of the most approved forms of timber bridges, derived from the large experience which had been gained in those parts of America where timber was readily obtained, and where other circumstances had led to its extensive employment on public works. Of course English Engineers preferred, if possible, using the most permanent materials; but there might be circumstances where a limited amount of capital, or a high rate of interest for money, might render it more economical to put up a cheap and temporary structure, to be renewed in a certain number of years. Any English

Engineer who had travelled in America, would agree with the remark, that many of the timber-trussed bridges were not put together in a way to answer the description which had been given of the well-executed structures referred to in the Paper, and he would observe that a cheap and rough description of work was not limited to timber bridges, but that it extended to the permanent way of railways, in which it was no uncommon circumstance to find ballast entirely omitted in the first construction: and although there might be rules for limiting the speed of the trains in passing timber bridges, his own experience was that the general custom was to travel without checking the speed, even over timber bridges of very doubtful security.

He agreed that one great fault in the timber bridges used in America was their liability to destruction by fire. Numerous instances of such destruction had come to his knowledge when travelling in Canada and the Northern States of America; and although he had not seen many watchmen in charge of timber bridges, he had noticed the evidence of contemplated risk in the frequent presence of water-tanks near the bridges. This risk of fire was perhaps in America the most serious objection to the use of these large timber bridges; and it was difficult to estimate the evils which might arise, either through loss of life consequent on the destruction of a bridge by fire, or the unavoidable and serious interruption of traffic, after a bridge had been so destroyed. In 1857 he had examined and reported on the Grand Trunk Railway of Canada, where the bridges executed by the Company were all of a character as permanent as those of an English railway, but on the line between the Atlantic and the St. Lawrence, which had come into the Company's possession, the numerous large river bridges were almost invariably of one, or other of the forms which had been described; and having reference to all the circumstances of the case, to the increased facility in the introduction of iron, and to the fact that a large number of these bridges, however good in design, had not been executed with that care which was essential to make them safe structures, and considering also the great risk of fire during the hot and dry summers of that country, he had thought it his duty to recommend, in every case, the substitution of wrought-iron girder bridges, at the earliest possible period.

At the same time he thought Engineers were too apt to look upon structures of wrought-iron as being of an absolutely permanent character. There was always a deteriorating action going on in them to a greater, or less extent; and where box girders were used, or any structure not of the simplest form, and perfectly accessible for repair, and for protecting all parts, by paint, from atmospheric influences, this deteriorating action might, in a few years, reduce to a most temporary character, and even to a dangerous condition, some bridges which were considered as being necessarily durable, because they were made of iron: and whilst many wrought-iron bridges were undoubtedly monuments of genius, ability, and courage, he thought the time would come when, if wrought-iron bridges were not looked upon as being 'pro tanto' as temporary as wooden ones, they would not be adopted by English Engineers, in some of their present forms, so generally as was now the case.

Mr. A. S. ORMSBY stated, that he had been informed by the President of the Richmond and Petersburgh Railway, that the expense of the insurance of the bridges on that line, which were all of wood, amounted to 15 per cent. upon the cost of each bridge.

Mr. COCKBURN CURTIS observed, that when employed upon railways in Spain he had some opportunity of witnessing the great expense, annoyance, inconvenience, and interruption to the traffic, which arose from the employment of timber bridges and viaducts. To effect a saving of first cost, many of the bridges of the lines, in the central portion of Spain, had been constructed of timber. But the subsequent outlay for repairs and renewals certainly could not have been less than that stated by Mr. Zerah Colburn in reference to the American lines. Another drawback to their employment in Spain was their liability to be burnt in the pronunciamentos and insurrections, to which that country, unhappily, seemed chronically liable. While Mr. Curtis was in Spain the large bridge across the River Turia, near Valencia, had been so destroyed, and owing to the cost and danger of using timber, the leading lessees and empresarios of the main lines, in the central portion of Spain, had determined upon substituting iron girders for the original timber structures.

Mr. SHEILDS thought some additional information was required as to the details of construction. Every one dealing with framing, whether of wood, or iron, knew that the method of joining the separate pieces, or parts together was the most critical point to be considered in the design. He had known failures occur from a bolt, passing through two timbers, tearing a piece of its own width out of the end of the wood, and from other causes, while the middle part of the timber was generally secure. Some details as to these points would therefore be valuable to those who had to use framings of timber, or of iron and timber in combination, and he was rather disappointed at not finding them fully given in the Paper. The whole of the structures which had been described, appeared to have been designed upon the principle of diminishing the strain upon the top and bottom, by using framings of very great depth; and this principle seemed to be carried to such an extent as to make them top heavy, and he thought it was altogether a form of construction which Engineers in this country would scarcely venture upon. The only other point was as to the cost. The first cost per lineal foot appeared to be from one-half to two-thirds of the cost of wrought-iron bridges in this country: and there was no doubt, looking at it in a commercial point of view, and even irrespective of the danger from fire and other such circumstances, that the balance of economy would be much in favour of iron structures, owing to the want of durability in the timber bridges, and the heavy outlay required for their maintenance.

Mr. A. GILES said, there was one point which had not been touched upon, viz., the difficulty of repairing wooden bridges of large span, on single lines, without stopping the traffic. In case of fire the stoppage of the traffic was inevitable. This was one of the principal objections to wooden bridges: another was the expense of watching. He had examined and reported on a line in Canada which had nearly 4 miles of wooden bridges, and which cost for watching above £2,000 a-year; yet even that was not always effectual. He had recommended the large spans to be reduced, wherever it was practicable, so that in case of accident or decay, the renewal of the bridge could be more easily executed.

Captain MOORSOM said, that after what had fallen from the previous speakers relative to wooden bridges in America, the journey to Plymouth ought to be regarded as wilful seeking of danger, on account of the numerous timber structures on the line; yet he had to go very frequently over it, and he had done so in safety for many years past: and going further on into Cornwall, such structures were even more numerous than in Devonshire, over which many thousands of passengers had passed in safety. He therefore thought the experience of these structures in England was not so generally adverse to them as appeared to be the case in America.

He exhibited a sketch, by one of his assistants, of a lattice bridge of 90 feet, or 100 feet span, which had been built under his direction between 1837 and 1840. On the Birmingham and Gloucester Railway he had erected at least a dozen of those bridges. Having left that line, and not being interested in the maintenance of it, he took no trouble to inquire about these bridges till the year 1854, when they had been at least fourteen, or fifteen years in use. He then wrote to the Resident Engineer to know what had been the cost of repairs, and the answer was that the Company had been at no expense, except that of repainting them from time to time. The timber in all those bridges had however been subjected to some preservative process. So far, therefore, as he might quote that experience, these bridges might be used with advantage in certain cases. This description of bridge had been erected by him usually on common roads, where economy was necessary, as the traffic was but small, and also in localities where they might be dispensed with hereafter at the fancy of the landowner. He thought in such cases the timber lattice bridge might be adopted with advantage. Mr. Mallet had erected for him a large lattice bridge in 1847 at Thomastown, over the River Nore,[1] and he believed it was still standing, without objection having been made against it. He would therefore express his decided conviction, contrary to the opinion of those who had spoken of the destructibility of the American bridges, that if timber bridges, and especially lattice bridges, were properly constructed, as they had been in this country, they might be adopted in many cases with perfect safety, and with great advantage in point of economy. Captain Moorsom added that he had found one great advantage of the lattice bridge to consist in the facility for repairs, and that he should have no difficulty in repairing a lattice bridge with a single track, while the trains were passing, provided it was of the ordinary character.

Mr. MALLET said the Paper did not give any information, as to the particular sort and quality of timber used in these structures in America. Practical men knew that there were three important elements which chiefly determined the durability of any timber bridge;—the quality of the timber, the way in which it was put together, especially the extent to which the joints were water tight, and the climate to which it was exposed. He was rather surprised at the very short life assigned to American timber bridges by Mr. Colburn, whose facts were nevertheless, he did not doubt, worthy of full acceptance in point of accuracy. It must, however, be borne in mind, that the climate of North America tried timber very severely; in addition to which he suspected, that the timber used was probably unseasoned, and not in all cases of the best quality. Upon these points, and whether due regard had been paid to the exclusion of moisture lodging between the opposing surfaces, he should deem it very desirable to have further information. The large annual expense for repairs and the short durability mentioned, did not quite coincide with European experience of wooden bridges. In the east of Germany, for example, it was well known that there were many wooden bridges, whose durability had been so great, that they were now actually objects of antiquity. The original bridge of Schaffhausen had stood, he believed, for more than forty years, before it was burnt by the French. The Germans and the Swiss, however, employed excellent timber, and they well understood how to put it together. In the case of the River Nore Viaduct, on the Waterford and Kilkenny Railway, alluded to by Captain Moorsom, Mr. Mallet's firm had been the contractors for the erection of that structure; the timber used was of admirable quality, the wales being pitch pine and the lattice bars choice crown memel. That viaduct was still standing, and was, he believed, sound, after being in use for fifteen years. He had passed over it last year, and it appeared to stand well. He had heard, however, that since Captain Moorsom had ceased to have charge of the line, piles and struts had been put in, forming a centre pier, and dividing the original long span of 200 feet into two spans of 100 feet each nearly. This appeared to him to be perfectly unnecessary—though it was only another example of a case that too frequently occurred, in which advice given by a second Engineer subsequent to the completion of a work by his predecessor, was based upon an assertion of original insufficiency.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xi., pp. 426–434.

February 24, 1863.
JOHN HAWKSHAW, President,
in the Chair.

No. 1,088.—"On the Reconstruction of the Dinting and the Mottram Viaducts." By WILLIAM FAIRBAIRN, F.R.S., M. Inst. C.E.

IN the early period of railways, the passage of rivers and deep ravines was frequently effected, to save expense, by timber viaducts and bridges, instead of by more substantial structures of stone, brick, or iron. This has been demonstrated, by experience, to be a mistaken economy; and although, with a limited capital, the Engineer has to adopt measures in accordance with his means, yet at the present time, considering the facilities afforded by wrought iron, there does not appear to exist any inducement for the introduction of a perishable material into structures intended to be of a permanent character. Previous to the application of wrought iron, in the tubular girder and other forms in which it is now employed, there might have been some reason for the use of timber, in order to reduce the first cost. But it is now generally acknowledged, that it is safer and more satisfactory to increase the estimates, than to incur the necessity of frequent repairs and renewals, the risk of accident, and the danger arising from the use of a material subject, like timber, to rapid decay. In the construction of works in which strength and durability are required, the Engineer is justified in availing himself of the material best adapted for ensuring permanency. For bridges and viaducts of great width and span, wrought iron is, probably, the most suitable. A wrought-iron girder, when properly proportioned, contains within itself the elements of lightness, with great powers of resistance to strain; and although, like all other materials, it is liable to oxidation and decay when exposed to the action of the atmosphere, it may nevertheless, with a little trouble and attention, be preserved for many years, in a state of perfect security. These considerations have more or less guided Engineers for the last fifteen years; and hence the immense increase in the use of iron for road and railway constructions.

The experiments for determining the strength and form of the Britannia and Conway tubular bridges led to a new era in bridge building. They developed an entirely novel principle of construction, which has been most successful. The many advantages resulting from the application of a tenacious, but flexible, material like wrought iron, both in plates and bars, may be estimated by the numerous structures of this class in almost all parts of the world.

From what has been already accomplished, it is probable, that, in bridge building alone, the use of this material will confer on Engineers the power of crossing rivers and deep ravines with spans up to 1,000 feet; and the time is, apparently, not far distant, when even greater spans may be possible, by the employment of a quality of steel possessing a much higher degree of strength and uniformity in its tensile character than iron, so as to enable nearly one-half the weight of the present constructions to be dispensed with. It may, therefore, be reasonably anticipated, that the improvements in progress in the manufacture of steel and iron will still farther extend the solidity of works, in every department of the useful and the industrial arts.

The Dinting[1] and the Mottram viaducts, on the Sheffield and Manchester Railway, were erected in the year 1843-44, under the direction of the late Mr. Joseph Locke, (M.P., Past-President Inst. C.E.) In the former there were five arches of 125 feet span, and in the latter, one of 150 feet and two of 125 feet span, all constructed of timber ribs on the laminated principle. At the springing of the arch, the ribs were fitted into cast-iron shoes, let into the masonry of the piers and the abutments. There were four main ribs in each arch of the Dinting viaduct (Fig. 1), and three in each arch of the Mottram viaduct; and these ribs were stayed by diagonal and cross braces. The uprights and diagonals in the spandrils were also stayed, and were morticed into longitudinal beams supporting cross joists, on which the permanent way was laid, at a height of 100 feet to 120 feet above the level of the river.

As is generally the case with similar structures, after a few years the ribs became twisted, and the entire structure of the Dinting viaduct was so insecure, that it had to be trussed diagonally with iron rods to retain it in line, and to prevent it from bulging over in a lateral direction. Within ten or twelve years after erection, the timber in both the viaducts was so much decayed as to endanger their security, and the Author was consulted as to the best means of reconstructing them in iron. The late Mr. Jee, then the Resident Engineer, undertook however, to render them secure, and after much trouble and expense this was considered to have been accomplished. But this did not last long, as, in 1858, they were again in such a state as to alarm the passengers and the people in the neighbourhood, who drove and travelled several miles to avoid crossing either bridge. Under these circumstances it was finally determined to renew them with iron, and the Author being again

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. v., p. 216, for "A Description of the Dinting Vale Viaduct," by the late Mr. A. S. Jee. Also, *Ibid*. p. 219, for a Paper, "On the Arched Timber Viaducts on the Newcastle and North Shields Railway," by Mr. B. Green.

Fig. 1.

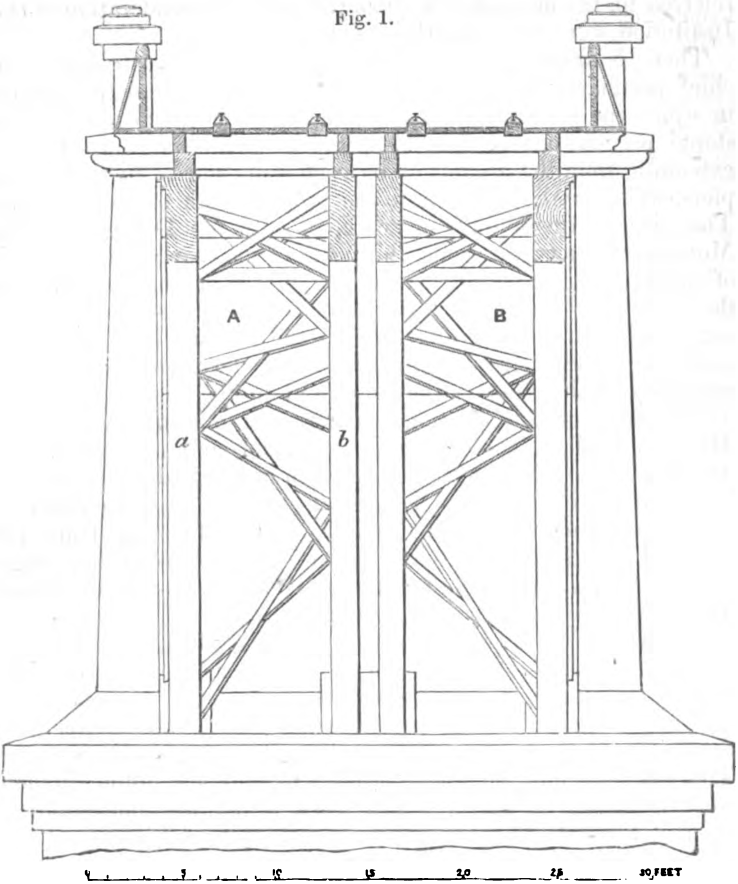

A
B
a
b
0
5
10
15
20
25
30 FEET

Fig. 2.

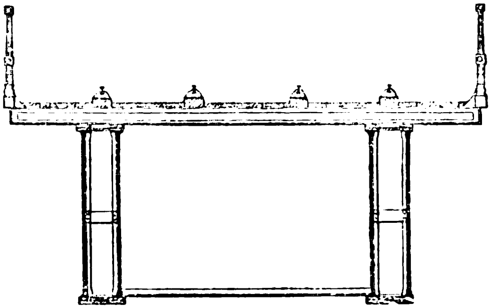


Fig. 1 shows the Dinting Viaduct as originally constructed ; Fig. 2, as restored.

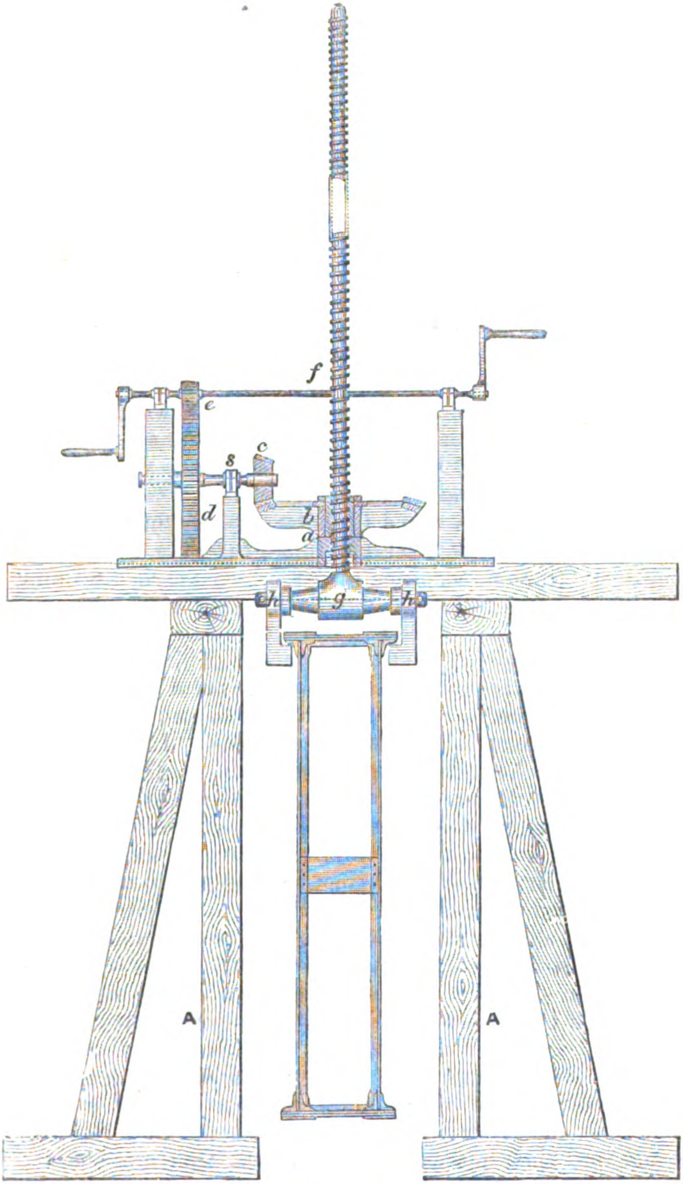
referred to, the designs, now submitted for the consideration of the Institution, were subsequently executed.

There is nothing novel either in design or construction, the chief peculiarity being in the mode of erection, and the manner in which the substitution of iron for wood was effected. The restored portions consist of two longitudinal tubular girders (Fig. 2) extending from the abutments on each side, and resting upon the piers, which were cut down to the proper depth to receive them. The girders are uniform in depth, in both the Dinting and the Mottram viaducts, being one-thirteenth of the span; and the areas of the top and the bottom flanges are in the proportion of 7 to 6, the breaking weight, equally distributed, amounting to 12·58 tons per lineal foot. The girders are riveted and united by covering plates over the piers, and are thus rendered continuous from one extremity to the other. They are fixed to the two middle piers in the case of the Dinting viaduct, and on one pier of the Mottram viaduct, and are free to expand and contract in the direction of the abutments. On the top of the girders iron cross-beams are riveted to the flanges, at intervals of 4 feet, and to these are attached the longitudinal sleepers for supporting the rails. The cross-beams project 3 feet 7 inches beyond the longitudinal girders, and upon their extremities the hand-rails are raised. The spaces between the longitudinal sleepers and the railing on each side are covered with planking 3½ inches thick, and upon this is spread a depth of from 3 inches to 4 inches of macadamized ballast, constituting the roadway of the bridge.

The principal condition insisted upon by the Directors was, that the traffic should not be interrupted during the progress of the works. This was agreed to, and it is satisfactory to state that, although there were from sixty-eight to seventy trains per day, no stoppage, even of a single minute, occurred, and that the whole of the work was accomplished without accident. In the prosecution of this undertaking, the Author incurred heavy responsibilities, and he was not free from anxious thought as to the results, and as to the best means to be employed. In this duty he was ably and cheerfully assisted by the Company's Engineer, Mr. Charles Sacré, and to that gentleman he is indebted for many useful suggestions.

As already stated, there were four ribs in the width of the Dinting viaduct (Fig. 1), but only three in the Mottram viaduct, the centre one of which was proportionally stronger. It was at first determined, in the case of the former, to construct one line of girders between the two ribs on one side at A, leaving the other side, B, untouched for the passage of the trains. But this could not be accomplished, as it was found that the space was too confined to permit the men to work; and the rickety state of the structure was such as to render the removal of any part dangerous,

Fig. 3.


f
e
c
s
d
b
a
h
g
h
A
A

Apparatus for Raising and Lowering the Tubes.

and there was considerable risk of the whole falling into the river below. It was then proposed to remove two side ribs, *a* and *b*, but that idea had to be abandoned, on account of their being the only support, as lateral stays, to the others, which were distorted and out of the perpendicular, as well as out of line. Finally, it was resolved to construct the girders on the top of the old existing platforms, to cut down the piers and the abutments, and, by a simple mechanical apparatus, to suspend the girders at each end, and lower them into their places. This arrangement was successfully carried out, and answered every purpose, as it not only allowed the old structure to be retained intact, but it enabled the contractors to finish their work on every girder, without obstruction to the riveters and their assistants.

The apparatus for raising and lowering the girders was exceedingly simple. A strong wooden frame, A A (Fig. 3), about 16 feet high, was erected on the pier at each end of the girder. On the top of this frame there was a cast-iron plate *a*, with a hole in the centre, through which a square-threaded screw, $4\frac{1}{2}$ inches in diameter, was passed. On this screw there was a bevil wheel *b*, having a brass bush, and resting on the plate *a*, which was increased in thickness to 4 inches round the hole; the meeting surfaces being covered with plates of steel and brass, carefully turned, so as to diminish the friction, when the girder, which weighed 80 tons, had to be lifted. Into the wheel *a* the pinion *c* worked, and received motion from the spur wheels *d* and *e*, the shaft *f*, and the crank handles on each side. On the lower end of the large screw was forged an eye, to receive the cross bar *g*, and at the extremities of this bar there were two links *h*, *h*, which hooked under the angle irons at the sides of the girders, at each end. From this description it will be seen that the operation was exceedingly simple, and with six men at the handles, the girders were raised, and lowered into their places, in the course of one hour from the commencement to their final settlement on the piers. When one line of girders was completed, and connected together over the piers, temporary wooden cross-beams were laid on the girders, in such a position as to allow of the permanent iron cross-beams being afterwards inserted between them; the temporary beams being partially supported on one side by the old centre arches, which had to be firmly stayed to the new girders. On these temporary cross-beams longitudinal bearers for supporting the rails were placed, and the permanent way having been fixed, the traffic was transferred to this side, during the operation of constructing and erecting the second line of girders. As soon as these were finished, and lowered into their places on the piers, the iron cross-beams were introduced between the temporary wooden beams, and when in place they were riveted to the main girders on the open side.

The longitudinal timbers were then bolted to the flanges of these cross-beams, the rails were permanently laid on that side, and the whole of the traffic was again transferred to it, until the other side was completed in the same manner. It will thus be seen, that there was no interruption of the traffic during the whole time of the reconstruction; and the last process was the riveting of the cross-beams to the line of girders first finished. The work of reconstruction of both viaducts was accomplished without accident, to the entire satisfaction of the Directors and of the public.

The communication is illustrated by three diagrams, from which Figs. 1 to 3 have been compiled.

Mr. **Bateman** said, it appeared to him that the most remarkable part of this work, was the manner in which the traffic of the line was maintained during the time the iron girders were being constructed and substituted for the wooden arches. He did not think the Paper described with sufficient clearness how that was accomplished; how in fact two iron girders could be made to take the place of four wooden arches, whilst the trains were running.

Mr. **Fairbairn** said, his object in bringing forward the Paper was to show the way in which iron girders had been substituted for wooden arches, without obstruction to the traffic, or danger to the public, during this difficult and critical operation. The Dinting and the Mottram viaducts had been erected about twenty years, and had undergone repeated repairs. When he examined the Mottram viaduct, one of the arches was so much decayed, as to cause the timbers to rise and fall from 3 inches to 4 inches during the passage of the trains; and in his opinion it was in so precarious a state, that it would have tumbled down within eighteen months, or two years. In fact, the passengers became so alarmed, that it was seriously proposed to run an omnibus to a distant station, in order to avoid crossing over the viaducts. It was necessary that the main girders should be constructed, be fixed in their places, and be made continuous, before the removal of any portion of the old wooden arches; and as it was found that there was not sufficient room to effect the reconstruction between the arches without danger, it was decided to build the girders on the top, at the same level as the rails. During the progress of the works the old timber arches were strengthened by the introduction of tie-rods and bolts. The traffic both ways was conducted first on one line of rails, while the girders were being erected for the other, and on their completion, it was transferred entirely to the second line of rails. This was effected without the slightest stoppage or interruption of any kind, during the whole process of reconstruction. The girders were originally constructed completely at the works, and were then taken to pieces in sections, reconstructed as separate girders, and when in place, were riveted together, so as to make them continuous from abutment to abutment. They were fixed on the central piers, and there were rollers on the abutments at each end to allow for expansion and contraction. The extent of expansion from the freezing point to summer heat, was about $\frac{3}{4}$ of an inch; and as the movement was in both directions, from the centre to the extremities, it was not considerable. In the Britannia bridge the possible movement would be about 2½ inches. Cutting out some of the cross braces to get the girders down was a delicate operation, owing to the want of lateral braces, the old ones being totally inoperative. It was feared that the new bridge might be ugly; but on the contrary, it had a very light and symmetrical appearance, even more so than ordinary arches, and was not without harmony in its general outline. The apparatus employed for raising and lowering the tubes was simple and effective in every respect. The diameter of the screws was 4½ inches, and the weight of the girder was 40 tons at each end. The pitch of the screw was about ¾ of an inch. In his opinion there was no economy in the erection of timber bridges in this country, when iron bridges could be built at so moderate a cost. The expense of the iron work in these viaducts did not exceed £20 or £22 per ton, including erection, and the cost was not increased by the peculiarities of the situation, or the circumstances under which the girders were erected. It was true that a certain deterioration was constantly going on in iron structures, particularly wrought iron, which oxidised more rapidly than cast iron; but with care and attention, a riveted plate, or lattice bridge of wrought iron, if occasionally painted and looked after to prevent oxidation, should last not only a hundred years, but for five hundred years.

Mr. HAWKSHAW, President, said the personal explanations which Mr. Fairbairn had given, in reply to questions from the Members, would he was convinced render this interesting work more fully appreciated. Every one must have been struck with the ingenuity which had been displayed, and the care which had been evinced, throughout the successful operation.

March 3, 1863.

CHARLES HUTTON GREGORY, Vice-President, in the Chair.

The following Candidates were balloted for and duly elected:—ALEXANDER BRYCE, JOHN FRASER, EDWARD HARRIS, FRANCIS CHARLES MIERS, GEORGE PADDISON, and GEORGE KENT RADFORD, as Members; GEORGE OSBALDESTON BUDD, Colonel GEORGE CHANCELLOR COLLYER (Royal Madras Engineers), JOSE MANUEL FARFAN, JOHN BARRACLOUGH FELL, WILLIAM PARSEY, HENRY PRINCE, STUART RENDEL, M.A., DOUGLAS SUTHERLAND, and WILLIAM MARSTON WARDEN, as Associates.

No. 1,074.—"The Perennial and Flood Waters of the Upper Thames."[1] By the Rev. JAMES CHARLES CLUTTERBUCK, M.A.

THE water-shed of the Thames comprises, and may be divided into, three geological districts,—the tertiary, the chalk, and the oolitic strata. A great portion of the first of these was subjected to a close investigation in 1851, when it was proposed to supply London with water from "the soft springs of the Surrey sands." The second was the subject of communications to the Institution in 1842 and 1843.[2] It is the third, though not strictly confined to its limits, that is the subject of this Paper. Geographically it is that portion of the water-shed, north of the range of chalk hills, bounding the vales of Aylesbury and of White Horse, and it extends to the Cotswold Hills, bounding the vale of Evesham and the valley of the Severn; and it has a computed area of 1,500 square miles. The river is spoken of as the Thames, the name it bears from its very source in Saxon records, and by which it is known to the inhabitants of the district through which it flows.

The subject is a complicated one, but it will be simplified by describing the tributaries in the order in which they join the main stream, which rises from the great oolite at Thames Head, about 4 miles west of Cirencester, near the Tetbury road station, on the Gloucester and Cheltenham Branch of the Great Western Railway. The Thames within 3 miles of its source passes from the oolite to the Oxford clay, over which it flows till it cuts through a gap in the coralline oolite at Sandford, below Oxford. It then passes to the Kimmeridge clay, turns the escarpment of the lower green-sand at Culham, touches the gault clay at Long Wittenham, whence it passes over a shelf of the lower green-sand, and returns to the gault above its junction with the Thame stream, the limit of the district now under consideration.

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[1] The discussion upon this Paper occupied portions of two evenings, but an abstract of the whole is given consecutively.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. ii. (1842), p. 155, and (1843), p. 156.

Thus the Thames runs over a clay bed, and is the mere carrier of waters derived from its tributaries. Those which run from north to south and from north-west to south-east—as the Churn, the Coln, the Leach, the Windrush, the Evenlode, and the Cherwell,—carry their perennial waters from oolitic sources. Those flowing from south to north have their sources in the chalk hills, from the escarpment of which they receive the back drainage, slightly augmented by that of the upper green-sand, and then pass over the gault and the Kimmeridge clays, either to the main stream, as the Ray and the Cole,—or as affluents of the Ock and the Thame, which are the main sources of the waters carried by these tributaries into the Thames. The Swill Brook is a sluggish stream, little more than the carrier of the flood water from the surface of the Oxford clay, on each side of the Cheltenham Railway, between Purton and the Cirencester branch. With this may be classed several brooks of the same character, which receive an insignificant quantity of perennial water from the oolite, though, from the extended surface of clay they drain, they carry large quantities of flood waters into the Thames above Cricklade. Thus, the river is a carrier of flood water immediately below its source.

The Churn rises just within the escarpment of the oolitic hills near Cheltenham; the geological condition of its sources is a type of most of the streams which derive their head waters from these strata. The inferior oolite, capped to the west of the Evenlode by the great oolite, and the great oolite to the east of that river, rest on the upper or lower lias clay and intervening marlstone. The water falling on the surface sinks into these strata, till it meets with the lias clays forming the bottom of the numerous valleys by which the district is furrowed. The springs often issue at so high a level above the foot of these valleys, that the villages are supplied with water led by pipes into tanks and troughs. It is from the aggregation of such streamlets, augmented frequently by springs from the marlstone, where its surface is exposed, or where it is thinly covered by the upper lias clay, that the Churn, the Coln, the Windrush, the Evenlode, and the Cherwell derive their head-waters; which may be termed perennial when sufficient in volume to drive a mill. As they approach the river, they intersect the upper strata of the great oolite, of which they receive the drainage, often thrown out at various levels by the frequent bands of clay found in these strata,—such as the fullers' earth and the clays of the forest marble, which prevent an accumulation of subterranean water sufficient to produce copious springs. The Churn with its affluents comes within this general description. It has one of its chief perennial sources in the well-known Seven Springs or Wells, about 4 miles south of Cheltenham. It drives the first of several mills about 2 miles from this source; thence passes Cirencester, and carries a considerable body of perennial water into the river near Cricklade; though in dry seasons its volume is reduced, in a remarkable manner, as it passes from the lias clay to the oolitic strata. This phenomenon, which occurs in other tributaries flowing from and over the same strata, requires further investigation.

The Ray receives its water from a different source, and is a type of the streams flowing from south to north. It rises in the escarpment of the chalk range, whence it flows over a band of the upper green-sand, the gault, and the lower green-sand, then runs over a large surface of Kimmeridge clay, cuts through the coralline oolite, (from whence, by its branches, it receives a small addition of perennial water,) then passes to the Oxford clay, and reaches the river near Water Eaton, between Cricklade and Lechlade. The volume of perennial water it receives from the chalk is shown by several mills near its source. It is the carrier of a considerable amount of flood water, from the surface of the Oxford clay in the neighbourhood of Swindon.

The head-waters of the Coln rise in a valley of which the geological condition is much the same as the Churn. From the ridge which separates Charlton Abbots from Brockhampton, the water flows into the Severn to the north, and into the Thames to the south. The first mill is at Syreford, which receives its chief power from a spring at its head. It brings down but little flood water to its junction with the river, immediately below the first lock of the Thames and Severn Canal. The Cole is of the same character as the Ray, rising under the escarpment of the chalk, driving several mills near its source, and carrying a considerable amount of flood water to the river. The Leach and several small streams spring from the oolite.

The two principal remote sources of the Windrush are in a valley at Cutsdean, and near the old jockey stables at Spring Hill. The several branches form one stream above Burford, and supply water-power to important manufacturing mills at Witney. Though rapidly augmented by heavy rains, this river does not bring down much flood water.

The Evenlode differs in some important respects from the streams before described. The head-waters of its north-west branch are found to the west of Moreton-in-the-Marsh, situated in a flat, the lower lias clay forming the surface. The perennial waters are mere threads, issuing from the oolitic hills above; their chief drainage falls into the Windrush. It is not until the waters of this branch of the Evenlode are augmented from the oolitic strata flanking the valley, through which it descends, that they are sufficient to drive a mill. The extended surface of lias clay throws off much flood water, which is carried down by this branch of the Evenlode. The branch from Chipping Norton, though it brings down much land drainage, is of a more perennial character. The Glyme, which it receives as a tributary below Blenheim Park, derives its water chiefly from the oolitic strata, and for this reason brings down little flood.

The Cherwell drains the most northern portion of the water-shed of the Thames. Its perennial waters are derived from the oolitic rocks, augmented by the drainage of the marlstone, a large surface of which is exposed in the district. The Oxford canal runs through the valley of the Cherwell, and is supplied, at its summit and at various points, by its waters. The gaugings of the Boddington reservoir, from which the summit level of the canal is sustained, afford a good indication of the character of the supply to the river. This reservoir receives a certain quantity of perennial water from the strata above the lower lias clay, and its area, of 65 acres, is sometimes raised, by heavy rain, more than a foot in twenty-four hours. It has never failed to supply sufficient water for the summit level of the canal. Soon after passing the outcrop of the Oxford clay the Cherwell receives the waters of the Ray, the northern branch of which drains the country round Bicester. The eastern branch serves as the carrier of the flood water of a large and very flat district of the Oxford clay, known as Ot Moor. The bed of this branch has frequently been dry, though it drains a water-shed of about 30 square miles. There are not any mills on either branch. The Cherwell is one of the chief sources of flood water to the neighbourhood of Oxford. A small stream, issuing from the coralline oolite near Headington, drives an overshot mill, and may be reckoned among the sources of perennial water. Those received by the river between Oxford and Abingdon are inconsiderable. The next tributary is the Ock, running from west to east on the Kimmeridge clay, near the margin of the outcrop of the coralline oolite, from which it receives a portion of its perennial water on the north. Its chief sources are from the foot of the escarpment of the chalk hills flanking the vale of White Horse to the south. The stream which flows from two heads at Letcombe to the south-east of Wantage is the largest of these; it drives several mills scarcely a mile from its sources. One streamlet from the north, rising in the oolite, drives a small mill at Sandford. Several smaller brooks running from this source in the same direction sink, by swallow holes, into the rock; the water rises again to the surface, when the overlying Kimmeridge clay is pierced, by artesian borings, as at Abingdon. As the gault and Kimmeridge clays are not separated in the vale by the usually intervening lower green-sand, a considerable body of flood water is thrown from their surfaces. From the flatness of the strata, and consequently little fall in the river, there are but three mills above Abingdon, just below which town the Ock falls into the Thames, close to the termination of the Berks and Wilts canal, to which it runs parallel through the vale. A small stream rises at Betterton, to the east of Wantage, also from the chalk. It drives a mill at Ardington within a mile of its source, and its waters are slightly augmented by the drainage of the upper green-sand; through the undulations of which it flows diagonally in its passage to the river at Sutton Courtney; between which place and Ardington it drives several mills. These streams are rapidly replenished by heavy rain, much of which is readily absorbed and re-delivered by the upper green-sand, but they carry little flood water. A few brooks and streamlets bring down small quantities of perennial water from the upper green-sand to the south, and the lower green-sand here found to the north. The flood water from the surface of the gault, which is exposed to a larger extent than elsewhere near the Didcot Station, is considerable, and drains away slowly from the little fall from this spot to the river.

The last of the tributaries is the Thame. The geological condition of its water-shed is, with some exceptions, the same as the Ock, though its course is in the opposite direction, flowing from east to west. Its bed is principally on the Kimmeridge clay, but it passes to the gault, at the point where these two clays run together, before it reaches the Thames near Dorchester. It receives the drainage of detached patches of the lower green-sand and Portland oolite, strata which are absent in the vale, but are found in situ above and below the Kimmeridge clay respectively. None of these streams are sufficient to drive a mill. The chief source of its perennial water is, as in the case of the Ock, the escarpment of the chalk hills, and the upper green-sand. There is much flood water from the extensive clay surface of the water-shed, and the river bed is choked and grown up at many points, thus seriously obstructing the passage of the waters. The mills on the main stream are few.

Such are the tributaries of the Upper Thames. The geological condition of the source of the main stream is worthy of especial notice. The oolitic strata at the Thames Head crop out from beneath the Oxford clay: as the junction of these strata is covered with oolitic gravel and debris, it is difficult to determine its exact point. The water falling on the oolitic rock sinks into, and accumulates in these strata, and is restrained from escaping below a certain level by the overlying clay. As the water rises in the oolite it shows itself above ground, where the surface is depressed; and it is in such a depression, which appears to have been further artificially excavated into a shallow well, now nearly filled up, and overgrown with the ash and hawthorn, indigenous to the valley, that the Thames is reputed to rise in Trewsbury meadow, about 10 feet below the summit level of the Thames and Severn Canal. In its normal condition it was probably a perennial source, whose volume was regulated by the elevation and depression of the water level in the surrounding oolitic rock, which rises to a considerable elevation on the opposite side of the canal. Augmented in its course by kindred springs, it carried a river of considerable volume over the outcrop of the Oxford clay, from whence it could receive no increase of perennial water, except a small quantity of soakage from the bed of gravel by which the clay is covered, at and below the outcrop of the oolitic rock. Thus, it is not without reason that there is, in a Charter of Caedwealha, 19th August, A.D. 688, this description of a boundary at Kemble, of lands given to St. Aldhelm, "usque famosum amnem qui dicitur Temis." Besides, it lies further to the west than any other considerable source; and it may be, that its naturally intermittent character caused it to be honoured by a superstitious people. In 1852, and again in the spring of 1862, the water flowed in a large volume from this source, and even higher up the valley it showed itself above ground. The Thames and Severn Canal was formed in 1789. When the natural sources fail, a large quantity of water is lifted into the summit level of the canal from a well on its brink about half a mile below Thames Head. The well is 14 feet in diameter, and is sunk 63 feet below the surface of the canal, or about 50 feet below Thames Head. At the bottom two adits, said to be about a quarter of a mile in length, are driven east and west, that to the west in the direction of the head, that to the east to a spot whence another source usually springs. The engine works a pump with a length of stroke of 9 feet, and has a cylinder 33 inches in diameter. In September 1862, it was making an average of eight strokes per minute, with a decreasing depth of 14 feet of water in the well; then no flowing water was to be seen in the bed of the stream above Ewen, a mile and a half below the engine, or 2 miles from the head. The mills below were deprived of nearly all their water, and though the Thames receives the contributions of the Swill and other brooks before spoken of, it carries very little perennial water to its junction with the Churn at Cricklade.

As the bed of the river is on the Oxford clay from Somerford Keynes till it passes the coralline oolite at Sandford, below Oxford, and as there is little difference in its physical, or geological condition between these places, it may be described in general terms. The whole natural bed of the river is an excavation in the Oxford clay, flanked to the south by the escarpment of the coralline oolite, which rests on a ridge of the clay. As a rule, the lower levels of the valley, including also in many places the oolitic rock, outcropping to the north at a very slight angle beneath the Oxford clay, are covered with drift gravel. Wherever the floods have extended, sand, silt, or argillaceous loam, has been deposited on this gravel; and this action is still going on, governed by the number and character of the floods. Thus, the bed of the river is as a rule gravel, and the banks a warp, the accumulation of ages. As the set of the current wears away the face of the bank at one point, a deposit is made elsewhere; the silt and warp settle in the eddies, and flags and rushes grow upon it, and a (so-called) flam is formed. If this should cause an obstruction to the ground-ice in its passage down the stream, the stones and other substances raised by it from the bottom add to the accumulation; which gradually rises as a bank to the river, and then receives the heavier portions of the sand and silt in floods, the lighter or argillaceous particles of the warp being carried inland. At length the whole assumes a level surface, with a slight inclination from the river to a point, usually on, or under, the level of the navigation high-water mark. There are instances of the change of bed to the extent of several chains in width; and indeed there appears to be no limit to these deviations, but the physical features of the valley. These facts have an important bearing on any improvement, so much needed, in the drainage, or condition of the Thames Valley.

The perennial waters are either used for mills or for navigation. The mills on the tributaries are numerous. Between Thames Head and Cricklade they are, as already shown, virtually deprived of water. That on the parent stream near Cricklade is said to be short of water; another close at hand on the Churn is assisted by steam power. It may be, that the Churn is affected by the pumping-engine near Thames Head. Therefore no gaugings of these streams would be a guide to the natural yield of water from the district which they drain. Between Cricklade and Lechlade the water is not applied to any economical use; and again from Lechlade to Wolvercot, three miles above Oxford, there are no mills. Above Wolvercot a portion of the water is diverted to Wytham, and this, together with the main river, is broken into a perfect network of mill and other streams in and about Oxford, which unite at Kennington above Sandford, where there is a large paper-mill. There is a corn-mill at Abingdon, and another paper-mill at Sutton Courtney, the last within the district ending with the confluence of the Thames and the Thame stream.

It has been shown that the Thames is merely the carrier of water, whether perennial or flood, brought into it by its tributaries; therefore the gaugings of these tributaries, where they join the main stream, would give the aggregate of water that it carries. As, however, such observations have been neglected, there are no available existing data on this point. The tributaries are so numerous, and their water-shed so varied, that any estimate of their volume at different seasons would be difficult. The effect of rainfall on streams issuing from the chalk stratum, for instance, is made a matter for calculation. Not so the waters of any one of the tributaries of the Upper Thames, most of which are immediately affected by heavy rains and subject to flood; but for this reason, as connected with land drainage, supposed to tell upon the flooding of rivers. On the accompanying map (Plate 7), those streams only are marked which have sufficient volume to drive a mill. Those rising in the chalk stratum have this power from their source. This is some guide to their volume, which might be easily gauged periodically; but as, in their passage to the main stream, they receive water from other sources, often suddenly augmented by summer rain and winter flood, the gauging of these streams would require incessant observations. This remark applies even in a greater degree to streams from the oolitic rocks, where the interlacing of clay with pervious beds is so marked a feature, and makes the discharge of water very complicated. The gauging of the main stream is beset with other difficulties, as the height and passage of the water is divided between the mills and the navigation, controlled indeed by stringent legal enactments, but too often disregarded.

Though the object of this communication is rather to draw attention to the nature of the water-shed, than to deal with absolute quantities derived from the various sources; the following gaugings are given, taken at a point on the river well fitted for observation, and will yield, if carried on in other places, valuable results. There are no mills for thirty miles above Wolvercot, and the navigation, though 'flashes' are still sent down, has virtually ceased. The manager of the mills at Wolvercot, has found, as the result of several years' observation:—That in the summer months, the branch of the river supplying Wolvercot mill has a mean velocity of 58 feet per minute, and a yield of 8,120 cubic feet per minute; at the same time, there is a further quantity of 3,500 feet passing in the Wytham stream, giving a volume of 11,620 cubic feet for the main river.[1] This is exclusive of the additional quantity brought down twice a week by 'flashes,' which last two or three hours, and are difficult to estimate. During the winter months, in fine weather without frost or rain, the river has a mean velocity of 94·9 feet per minute, and taking the sectional area as 181·5 square feet, this gives a volume of 17,224 cubic feet per minute; to this must be added, on account of the Wytham branch,

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[1] This quantity was reduced to 6,849 cubic feet in the summer of 1864.—J. C. C.

5,400 cubic feet, making the volume of the main stream 22,624 cubic feet per minute. In moderate rainy weather, without floods, the total quantity of water passing through the mill, lashers, and weirs in connection with it, is 28,189 cubic feet per minute. With this quantity, the level of the river reaches the high-water navigation mark, but it does not at any part overflow. In floods, the river rises from 6 inches to 18 inches over the banks, and extends over a large area of flat meadows, so that the yield cannot then be ascertained at this part of its course. At the end of December, 1862, gaugings were taken of the whole stream at a period coinciding with the last example, namely, moderate rainy weather without flood. The total yield was then 35,498 cubic feet per minute, of which 27,986 cubic feet may be taken as representing the quantity passing through the mill, &c., at Wolvercot, given in the previous example as 28,189 cubic feet, and the remaining 7,738 cubic feet, as the water passing from the main stream to Wytham. These data suggest the necessity of adopting a standard at various stations, so that the results may be compared with the rainfall when the gaugings are taken, and also of fixing on localities where the flood waters of the tributaries and of the main stream may be gauged. This obviously must be a work of time, and requires patient and repeated observations. When these latter gaugings were taken, observations of a similar character were made on the river below the influx of the Cherwell and the Ock, which gave 50,995 cubic feet per minute, a difference of 15,497 cubic feet per minute as compared with Wolvercot. Of this quantity, it was estimated that 7,689 cubic feet per minute were brought into the main stream by the Cherwell, and the remainder by the Ock and smaller perennial streams. The verification of the quantity in the Ock was prevented by a fall of rain of 0·48 of an inch, or nearly half an inch in a few hours. At the expiration of thirty-six hours, the volume of the Thame stream was doubled, and about 30 per cent. was added to the volume of the main river. At Wolvercot, on the 5th January, 1863, after about 1 inch of rain, the increase was from 27,986 to 48,418 cubic feet per minute.

The rainfall from the 1st to the 7th January, 1863 inclusive, produced a flood in the Thames under circumstances peculiarly favourable for observation. The rainfall recorded during that period was at—

	Inches.
Oxford (Central) . . .	1·74
Banbury (North) . . .	1·30
Cirencester (West) . . .	1·50
Hartwell (East)	1·28
Wittenham (South) . . .	2·27

This gives an average of 1·61 inch over the whole water-shed.

Dalton's gauge at Hemel Hempstead, for the same period, showed a total fall of 1·52 inch, the percolation being 1·10 inch. The gaugings of the main river at Wolvercot then amounted to 82,500 cubic feet per minute, and at Clifton Hampden, below Abingdon, to 181,832 cubic feet per minute. Of this latter quantity, 44,755 cubic feet, or an increase of 37,066 cubic feet as due to the flood, were delivered by the Cherwell, 24,864 cubic feet by the Ock, and 29,713 cubic feet by the many smaller streams, water-courses, and land-drainage outfalls, issuing into the river between Wolvercot and Clifton Hampden, from a computed water-shed of 80 square miles. The latter quantity was on this occasion much increased, by the rainfall on the southern part of the district being in excess half an inch; the brooks and water-courses bringing down the drainage from the gault clay were consequently much swollen. These gaugings show the quantity of flood-water from some of the tributaries, which issue into the river between Wolvercot and Clifton Hampden, a distance of about 20 miles by the river, with an average fall of 2 feet per mile. The gaugings of former floods cannot be given, but the following comparison of floods is not without interest:—

Date.	Rainfall.		Dalton's Gauge.		Rise of Flood above H.W.Mark.
	Duration.	Quantity.	Rainfall.	Percolation.	
	Days.	Inches.	Inches.	Inches.	Inches.
1852, Nov. 16. .	27	5·25	..	..	81
1862, March 29 .	27	3·09	3·90	2·70	62
1863, Jan. 10 . .	7	1·62	1 52	1·10	42

When gauging stations have been fixed on, the quantity of flood or perennial water flowing down the river may at any time be ascertained; but up to the present time there is no available information on this interesting subject.

The navigation of the Thames is of very ancient date. A toll of salt fish (herrings?) was levied by the Abbey of Abingdon before the Conquest, on boats passing from Oxford through a new cut made for their accommodation. From that time it has been the subject of frequent legislation. It is now under the control of Commissioners, and is divided into six districts, of which that between Lechlade and Oxford is the sixth. It was a remark of the late Dr. Buckland, that no lines of inland communication could flourish, except they ran tranversely to the lines of strata, as their variation ruled the products, and the internal commerce of the country. This is fully exemplified in the sixth district of the Thames navigation, which runs on one stratum, the Oxford clay. From this and other causes it has virtually ceased to exist. The physical condition of its bed, and its easy gradients, offer facilities for navigation. The whole fall from Lechlade to Oxford, 31 miles, is only 51 feet 3 inches, or about 1 foot 7½ inches on an average per mile. Some of the pound locks belonging to the Commissioners are in a hopeless state of dilapidation. The weirs, chiefly the property of individuals, and of a construction little improved since the days of the Saxons, are almost exclusively used for fishing purposes; often to the injury of lands near or adjoining the river, and of little profit to those who own or rent them. The shutting tackle, as it is called, consists of a cill fixed at the bottom of the river, upright posts, called rimers, fitting at given distances to the cill, and removeable; there are also two sets of moveable flood gates, called ground gates, and overfalls, the one fitting above the other in the spaces between the rimers; also two cross-beams parallel with the cill, against which the rimers, and the handles of the flood gates rest, and are kept in place by the force of the stream. One of these beams swings like a lock gate on a pivot, to allow the boats to pass, when the weir is drawn, and the rimers on one side are removed. On the passage of every boat or barge, the water on either side of the weir is drawn nearly to a level. There are eleven such weirs still in existence between Lechlade and Oxford, two having lately been removed. There are but three pound locks. It would now be very difficult for a boat to pass the whole distance at the time of low water. Flushes, or flashes, are still paid for, by a sort of tariff, levied by the owners of the weirs as far as Langley weir, above Eynsham, to enable boats to travel below. From Oxford, the flashes are arranged, during seasons of low water, for two days in the week, beginning at Oxford on Monday and Thursday, and reaching the district below on the following days. Under these regulations the interests and convenience of the navigation and of the mills are necessarily at variance. The economical use of the water, when most needed by the mills, is sadly interfered with, by suddenly sending down an excess on 'flash' days, and by penning it back, to replenish the vacuum above, when the flash has passed. The rising and falling of the water, with an alternating wet and dry surface, tends to the disintegration of the banks, and in various ways inflicts injury on the mills and on the landed property. The present depressed state of the navigation forbids the hope of any improvements by the Commissioners. The first step towards any general change for the better must be, the abdication of their power, or the refusal to interfere in any case between Lechlade and Oxford. From Oxford, the perennial waters are not only used for navigation, which has been greatly improved of late years, but these waters drive many important corn and paper mills. Notwithstanding the extended and varied water-shed of the Upper Thames, its waters have often fallen very short, as in 1858. But for the heavy rainfall in the spring of 1862, a similar defalcation would have occurred in the summer of that year.

It has been shown, that the Thames is a river of floods almost from its source, increased by flood and land drainage brought down by the Ray and the Cole, and other smaller water-courses above the navigation. The lower oolitic rock cropping out from beneath the Oxford clay in the Thames valley to the north and the coralline oolite from beneath the Kimmeridge clay in the valley of the Ock, rise at so slight an angle from beneath those clays, that in wet seasons, these strata become so gorged with water as to throw it from their surface, either as flood, or by land drainage. Thus these pervious beds assume the drainage character of retentive strata, added to which, in the higher levels, the frequent bands of clay in certain localities, produce the same effect, and augment the flood water from the exposed surface of the lias clays in the valleys of the Windrush, the Evenlode, and the Cherwell, from the large tract of Oxford clay in the water-shed of the Ray, a tributary of the Cherwell, and from the Kimmeridge and gault clays in the valleys of the Ock and Thame. This geological condition at once accounts for the large body of flood water thrown into the Thames. It must be noticed, that in many localities these clays are covered with drift gravel, of which the depth is often so considerable, that the water sinking into it issues in springs, and so becomes perennial. These complications make it impossible to identify the respective sources of flood and perennial water, or to limit them to certain strata.

As the volume of flood water depends not only on the amount of rain, or snow, but on the circumstances under which it falls, it requires close and constant attention to determine the probable flood from a known quantity of rainfall. It has been observed, that it requires from 2·50 to 3·00 inches of consecutive autumnal rainfall to replace the summer evaporation. The highest recorded floods on the Thames since January 8, 1734, are January 17, 1764; March 10, 1774; and January 27, 1809, the highest on record, caused by the sudden melting of snow, by which bridges were swept away, and much damage sustained at Maidenhead, and other places; December 21, 1821, nearly as high as that of 1809; January 1842, owing to a sudden thaw; and November 16, 1852, caused by long-continued rainfall, amounting to 5·50 inches on twenty-six previous days, after an unusually wet autumn. There was also a very considerable flood March 29—31, 1862, to which the following observations apply. As the relative quantity of rainfall varies on so large an area as the water-shed of the Upper Thames, with tributaries flowing in opposite directions from its extreme limits, the records of rain-gauges at three stations, Hartwell, near Aylesbury (east), Banbury (north), and Cirencester (west)—are given for the months of March and April, and part of May, in Table I. The records of Dalton's gauge, communicated by Mr. John Evans (Assoc. Inst. C.E.), are added, because it may be presumed, that the water of supersaturation, which in permeable soils sinks to the subterranean water-level, in impermeable soils flows from the surface, or is discharged by land drainage.

TABLE I.

—	Hartwell.	Banbury.	Cirencester.	Dalton's Gauge.	
				Rainfall.	Percolation.
	Inches.	Inches.	Inches.	Inches.	Inches.
March	4·19	4·21	4·70	4·04	2·87
April	2·95	1·88	2·22	2·52	1·52
May 1st to 19th . .	2·32	2·51	2·30	2·73	0·87
Totals . .	9·46	8·60	9·22	9·29	5·26
Average .		9·09			
Level above the sea, in Feet	250	350	446		

The whole period has been divided into four portions, marking the alternations of the flood, Table II., and as it is known, that the direction of the prevailing wind affects the volume of the flood-water, this is stated.

TABLE II.

Date.	Hartwell.	Banbury.	Cirencester.	Wind.	Excess of Rain at
	Inches.	Inches.	Inches.		
March 5 to 11 .	1·24	0·98	1·40	Var. S. and S.W.	Cirencester.
„ 12 to 28	1·69	2·85	2·55	Var. N.E. to S.E.	Banbury.
„ 29 to April 11 .	2·10	1·75	1·38	N.E.	Hartwell.
May 5 to 16 .	1·92	2·47	2·30	Var. S.E. to S.S.W.	Banbury, and Cirencester.

The first period brought down little flood water, as the rainfall scarcely sufficed to replace the evaporation of an unusually dry February, in which only 0·49 of an inch of rain was registered, against an average of 1·53 inch.

In the second period, the river had sunk to high-water navigation mark on the 16th of March, and the flood attained its greatest height at Long Wittenham, between Abingdon and the junction of the Thames and Thame stream, on the 29th of March, at 4 P.M. It there occupied a sectional area of 2,546 square feet, of which 1,796 square feet may be accounted flowing water, with a central surface velocity of 240 feet per minute, and a mean depth of 11 feet. The periods at which the flood attained its greatest height at other points were as follow.—

On the Tributaries.

Witney (Windrush)	March 29th, NOON.
Somerton (Cherwell)	„ 28th, P.M.
Heyford „	„ 28th, 3 to 5 P.M.
Islip „	„ 28th, 4·30 P.M.

On the Main Stream,

St. John's Lock, Lechlade	March 29th, 6 A.M.
Newbridge	„ 30th, 12 NOON.
Eynsham	„ 31st.
Wolvercot	„ 28th and 30th.
Port Meadow, above Oxford	„ 30th, 12 P.M.

The variation at Eynsham is due to the influx of the water of the Evenlode, which, as has been shown, brings down a large body of flood-water from its source, due to the geological condition of its watershed. The water at Eynsham was thus penned back.

The record below Abingdon is as follows:—

Abingdon,—the mouth of the Ock	March 29th, NOON.
Abingdon, main stream	„ 29th, 2 P.M.
Long Wittenham	„ 29th, 4 P.M.
Crowmark Mill	„ 29th, 6 P.M.
Wallingford	„ 29th.
Streatley	„ 30th, 3 A.M.
Caversham, Reading	„ 30th, 8 A.M.
Henley	„ 30th, 3 A.M.
Marlow	„ 30th, P.M.
Windsor	„ 30th, P.M.

It will be seen, that the rise of the flood maintained a regular progression in its passage from Abingdon downwards. The excess of rain with a north-east and a south-east wind was from Banbury and Cirencester. Thus the flood encountered no obstruction from the waters of the Thame stream. The influx of the waters of the Loddon above Henley accelerated the rising of the flood at that point, five hours in advance of the increase at Caversham.

In the third period, from the 29th and 30th of March to the 11th of April, the flood fell, with slight pulsations of rise. The total rainfall on the 9th, 10th, and 11th was 1·40 inch. The wind during this period was from the north-east, and the fall of rain with the wind in this quarter was unusually great, the excess of rain being registered at Hartwell. The flood in the Thame stream attained a greater height than during the previous period, and in the main stream it was about 7 inches lower where measured.

During the fourth period, from May 5th to 10th, the wind was variable from south-east to south-south-west, with heavy and partial storms. The excess of rainfall was at Banbury and Cirencester. The flood in the Cherwell, and in the extreme west, rose higher than in the former periods. There are no generally available data, as to the volume of flood-water as compared with the rainfall. Any steps towards the improvement of the Thames valley should be accompanied by a well and regularly conducted series of observations on the volume of the perennial as well as of the flood waters. The latter can only be relied upon, when the volume of the flood requires the removal of all the shutting tackle at the various weirs and locks, so that free passage be given to the water throughout its course.

The action of land drainage on flood water is an important question. Land drainage yearly increases in area and in efficiency. Much information on this point might be obtained from large landed proprietors, who in some localities have drained thousands of acres; but the mere knowledge of the area drained would be no sure guide, without the quality of the work was also ascertained. Another question arises, are the perennial waters augmented, or diminished, by land drainage? It is universally admitted, that the floods in the main river and in its tributaries rise more rapidly than heretofore. In some localities there has been an advance of twenty-four hours in seventy-two hours within the last twenty years. There is a difference of opinion as to the subsidence of the water, and as to the total relative amount of flood.

As to the perennial water: On the escarpments and undulations of the lias and oolitic strata, where the sand or rock outcrops above the clays, the water often exudes so slowly, that it evaporates from the surface of the soil over which it is diffused. This is frequently the case, where these springy places are covered with a peat deposit, the accumulation of a long period. When deep drains are cut into such spots, the water is gathered into a small stream, and sometimes becomes perennial. This more than counterbalances the loss, where too free an outlet is given to sources already perennial, and by which their periodical exhaustion is accelerated. This remark applies to the drainage of the upper and the lower green-sand, and in some cases, to the water issuing from the escarpment of the chalk, and the drift gravel, resting on the various clays: the last are frequently laid quite dry by artificial drainage; at other times, when the water in them is tapped, they become perennial. As yet, land drainage has produced little apparent practical effect on the volume of the flood, or perennial waters of the Upper Thames; though it is probable that floods will be diminished, inasmuch as land drainage promotes winter evaporation, and increases the absorption of rain water by the soil.

There is great scope for improvement in the valleys of the Thames and its tributaries, especially the Thame, the Ock, the Cherwell, and the Evenlode. The antagonism in the interests of the mills and the navigation is an acknowledged difficulty. These are guarded, or restrained, by very definite laws, which also protect the landowners, though their provisions are seldom enforced, and are too often disregarded. Much might be done by the landowners, without affecting the rights or privileges of the mills or of the navigation, by a united and well-matured determination of purpose. After the great flood of 1852, a committee was formed, of which the late Mr. Pusey was the Chairman. A report was published, stating the amount of injury inflicted by the floods, but no action was taken upon it. During the year 1862, an application was made to the Home Office, by an influential Committee, headed by the Duke of Marlborough, to issue a Commission to inquire into the whole question; but as yet nothing has resulted from the interview with Sir George Grey. Under the powers of an Enclosure Bill, with the concurrence and assistance of several landowners, Mr. Bryan Wood has carried out some important works, by which the injury inflicted by the floods has been restrained. These works are based on a different system from that previously suggested. Mr. Wood separates the local drainage entirely from the flood. In describing the physical condition of the river, it has been shown, that in the gradual deposition of the warp covering the natural bed of the valley or vale, by the continued action of the floods, the surface has assumed an inclination from the river to a point at or under the navigation high-water mark. First, all communication with the river is cut off by embankments on both sides, a sufficient area being left within the river bed to carry off the ordinary flood water. Inside these embankments, channels are cut parallel with the course of the river, and of sufficient size to take the adjacent land drainage, as well as the surface drainage of the meadows. The water collected in these channels is then led down, and delivered into the river at a lower level. In the spring of 1862, the crops of hay on the unprotected land were spoiled in growth, or were carried away when cut, by the flood. At the same time, and close at hand, the hay crop on the protected meadows was cut and safely secured, whilst the flood water passed between the embankments, which were 2 feet or 3 feet above the surface of the land. As the winter floods are known to benefit the meadows, if the water does not rest too long upon them, the embankments are fitted with hatches, by which the flood can be admitted at will. In proof of the injury inflicted on the meadows by a protracted flood, it may be mentioned that, in the spring of 1840, the surface of a large tract of meadow (at the very spot where these improvements have been made) was covered by a substance of macerated vegetable matter resembling a felt of cotton wool. It was in many cases made into garments, and was worn by the farmers, to show the toughness of the material, and as tokens of the effect of a protracted flood. If, by some such system as that adopted by Mr. Bryan Wood, the floods were brought under control, and water prevented from remaining stagnant on the land, two great objects would be accomplished; the improvement of landed property, and of the sanitary condition of the Valley of the Upper Thames.[1]

The communication is accompanied by a series of diagrams, from which Plate 7 has been compiled.

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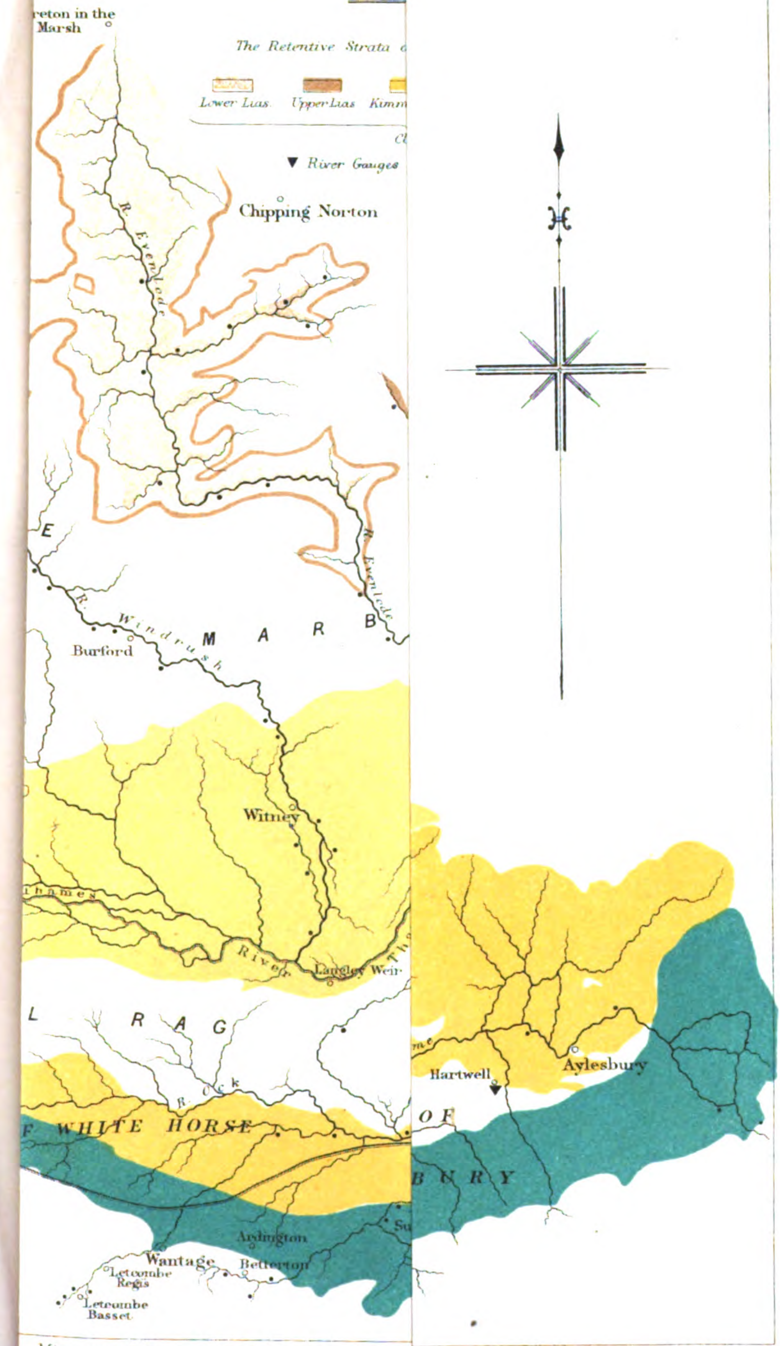
[1] Works are now in progress, executed at the expense of the Rev. R. Greswell, calculated to free part of Port Meadow, belonging to the freemen of Oxford, from stagnant water, by leading it to a large outfall.—J. C. C., Nov. 1864.

[The Rev. J. C. CLUTTERBUCK

UPPER

GEOLOGICAL MAP

PLATE 7 VOL. XXII


reton in the Marsh
The Retentive Strata
Lower Lias
Upper Lias
Kimm
Cl
▼ River Gauges
Chipping Norton
R. Evenlode
E
R. Windrush
Burford
M A R B
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Thames
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Ardington
Wantage
Letcombe Regis
Betterton
Letcombe Basset

Minutes of Proceedings, Institution of Civil

KELL BROS LITHO CASTLE ST HOLBORN

The Rev. J. C. CLUTTERBUCK said, there were many points to which he wished to direct special attention, both as regarded the nature and varied character of the water-shed, as well as to the question of the navigation and the mills. Some persons went so far as to say, that the navigation of the Thames must be discontinued, and the mills be removed, before any real improvement could be effected in the valley of the Thames. It was true that, as at present regulated, there was an antagonism in the interests of the mills and the navigation, and that by this rivalry damage was sometimes inflicted on the owners and occupiers of land, whilst the sanitary condition of the valley was affected. Now, he believed that, under proper regulation, both the navigation and the mills might be retained, not only without mutual injury, but also with benefit to the public. With respect to the sanitary condition of the valley, he begged to refer to the elaborate and valuable Memoir of Dr. Acland, on the Cholera at Oxford[1] and to the Report of Mr. T. Macdougall Smith, addressed to Mr. (afterwards Sir) W. Cubitt.[2] Referring to the geological rather than the engineering character of the Paper, he remarked that numerous failures in schemes for obtaining supplies of water had arisen from a want of sufficient knowledge of the geological condition of the strata whence water could be procured. It was now more than twenty years since he stated, that the aggregation of causes would produce some great effect upon the pumping under London. The bearing of agricultural drainage on water supply was a subject of growing importance, from the increase in the population of towns, and the large quantities of water now required by the inhabitants. The water-shed of the Upper Thames presented a great extent and every variety of agricultural land drainage. Though at first sight it might seem a contradiction in terms, yet he believed that winter evaporation was promoted by agricultural drainage. Evaporation depended on the condition of the atmosphere, and on that of the surface of the soil. There was little evaporation from the surface of water, but very much from a rough surface exposed to the air. This might be shown by a simple experiment. If two shallow vessels were filled with water, and into one a piece of brick, or some such substance, was introduced, then from this latter four or five times the amount of water would be evaporated in a given time, than from a surface of water alone; of course by the addition of the brick the surface would be increased, but not sufficiently so as of itself to account for the augmented evaporation. Thus, on the falling of winter rain, there would be a greater absorption of water on the drained surface; consequently, winter floods would be diminished by agricultural drainage. He had applied the recorded readings of Dalton's rain-gauge in a novel manner, by presuming that the quantity of water which flowed from the surface, or was discharged as flood by land drainage, was represented by the water of super-saturation percolating the gauge. The interest felt in this subject, especially at Oxford, was very great. Heretofore it had only attracted attention after unusual and disastrous floods; but he trusted that this spasmodic action would give place to some well-devised and determined action, and it was with this view that he desired the subject to be thoroughly sifted, by those who were best able to cope with the various difficulties that it presented.

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[1] "Memoir on the Cholera at Oxford in the Year 1854. By Henry Wentworth Acland, M.D., F.R.S.," &c. J. H. Parker, Oxford. London: J. Churchill, Burlington Street.

[2] "University and City of Oxford. Report of Sir William Cubitt upon the Sewerage and Water Supply." Amersham: W. Broadwater.

Mr. ALDERMAN TOWLE concurred in the opinion, that this subject was of immense importance to the inhabitants of the valley of the Thames. Having formed one of Mr. Pusey's Committee, consisting of six members, to which reference had been made in the Paper, having resided for many years at the lowest part of the Upper Thames, and having had the advantage of attending the practical discourses, delivered on the spot, by the late Dr. Buckland, he could claim to possess some acquaintance with the questions at issue. At Sandford, where all the streams met, there was a gorge, in form like the letter V, the rising ground on the east, which was in Sandford churchyard, approaching very close to that on the west at Bagley Wood. At this point an embankment had been thrown up, which was the only cause of the continuous floods round Oxford; for he contended, that no mill could cause a flood; it would simply divert the water from its course, throw it upon the neighbours, and soon after passing out of the river, it would flow in again. But in this case the mill produced a flood, because the valley, and not the river only, was dammed up. The highest fall in the Thames was upon the flat country, which here inclined towards Oxford. He looked upon this point as the grand mistake of the Thames Valley, and without it was altered, the drainage could not act, as all the disputes originated with the flood at this spot. This great evil arose from the lock at the entrance of the Sandford mill pond having been placed too high, in order, as it was supposed, to raise the high-water level. Before this alteration was made, barges of 160 tons could navigate this portion of the river, whereas now it was impossible for craft exceeding 30 tons to pass the same point. This was the gist of the whole question. It had been lost sight of by Engineers, in the general treatment of the Thames Valley, and had been got rid of in some way by the Thames Navigation Committee and other interested parties.

Mr. ALDERMAN RANDALL said, though he had no pretensions to scientific knowledge on this subject, he could bring the observation of many years to bear upon it. He was well acquainted with the peculiar features of the whole district of the Thames above Oxford, and could speak particularly as to the water being now brought down more quickly than formerly. Agricultural drainage had materially aided this, but he thought that larger operations had caused those sudden floods, with which the neighbourhood of Oxford had specially to contend. Above Oxford, there were some thousands of acres of meadow land, which formerly used to act as natural reservoirs, holding the water in suspension, as it were, and supplying the river by percolation through the summer. Across these meadow districts wide and deep channels had been cut, so that the water was no longer retained on the land, but was at once passed from the marshy grounds into the river; and any heavy rain-fall was, in like manner, conveyed more suddenly to the narrow part of the valley at Oxford, sometimes thus producing summer floods. At the large brewery of Messrs. Hall & Co., close to the old Castle Tower, at the back of which there were several low lying meadows, once belonging to the White Friars, there was formerly, as he was informed, considerable notice of a coming flood by the gradual rise of the river; whereas now the whole of the meadows were sometimes under water within a few hours. There could not be a more practical proof of the suddenness of the flow of water from the Upper Thames on to this district than was furnished by these facts, confirming as they did the opinion that the recently-made large cuttings, as at Aston Mead and at Standlake Common, across marshy districts, were instrumental in producing the evils described by Mr. Alderman Towle, as arising to the locality abutting on the narrow gorge of the river near Sandford. Besides this, however, it should be noticed, that it was at Oxford that the Cherwell flowed into the Thames, and the waters of that tributary were similarly swollen from the drainage of Otmoor Common. Prior to the systematic drainage of this extensive flat, it generally presented, through the winter months, the appearance of a large lake, from the hills, near Bicester, to the Beckley Hills, near Oxford; while now it was rare to witness such a flood after a heavy rain-fall. Even assuming that the natural autumnal fall had been to some extent taken up, by the lands being more thirsty than prior to the adoption of systematic drainage, the Cherwell, from the free influx of the surplus water through the deep channels intersecting the Otmoor district, would become more suddenly charged, and the mischief around Oxford would thus be aggravated, and the probability of flood be increased.

The Author had described the many sources of the perennial waters of the Thames, as well as the causes specially producing flood water. These sources and causes appeared as existing largely above the gorge at Sandford, which held back the water upon Oxford in flood time, owing, as he believed, to the natural formation of the Valley of the Thames at that point, and not to any other cause. Much weight was to be attached to the remarks in the Paper, as to the changing deposit of gravel and soil in the bed of the river. He had himself witnessed a special illustration of the bad consequences of this below Sandford Mill. In 1862 he inspected, in company with one of the University Professors, the state of the river, then swollen by flood water, from Oxford to Abingdon. At the lower pound gate at Sandford, the water was nearly 3 feet above high-water mark. On the same reach, with no works of any sort to intercept the flow, and nothing but the old island at Nuneham legitimately to break the course of the stream, on proceeding to Abingdon, just above the pound gates, it was found to be only 5 inches above the high-water mark. On an after-inspection of the course of the river on this reach, the cause of this was soon discovered, as the manager at Mr. Norris's mill at Sandford had anticipated. The channel was materially affected in many places by such deposits as had been alluded to, but especially opposite Nuneham Park, where, at the fork of the river formed by the old Island at the cottages, within the last few years the deposit had formed in the centre of the stream a new island, now planted with trees. Under such a state of things, it must be evident, that there would be considerable difficulty in the escape of the water from the upper and narrower part of this reach, and the singular difference in the respective heights of the water at its two extremes was easily accounted for. Remedies, however, had been suggested for the relief of the Oxford district, and rough plans of them had been placed in influential hands. These were suggested by an inspection of the measures adopted at Abingdon, for the discharge of the waters there, from the reach just spoken of, where, by means of a paved towing-path at high-water mark, the swelling waters were passed on as soon as they reached that level. The late Mr. Treacher, for many years the surveyor of the Thames navigation, pointed out, at Sandford and at Iffley, spots exactly suited for the application of similar means of relief. It was right to mention that at Sandford, Mr. Norris, the owner of the mill and of the land at the required spot, expressed his readiness to help forward this or any other reasonable plan, if his interests were protected, and means were provided for keeping in repair the projected works. Mr. Norris also added the reasonable request, that if the water was brought to the mill tail, the channel should be opened to Abingdon to relieve it. The drawings for long lashers, like paved towing-paths, 150 feet each at high-water level, both at Sandford and at Iffley, were placed in the hands of the Dean of Christchurch, to submit to the judgment of an eminent Engineer. He trusted that the efforts now being made would result in a well-devised measure, which, without prejudicing the landowners' interests, or injuriously affecting the navigation of the river, might improve the land throughout the whole of the valley, and benefit the sanitary condition of Oxford and its vicinity.

Mr. J. H. **Taunton** said, with regard to the early sources of the Thames in Gloucestershire, the springs at Thames Head, which had been spoken of as the principal feeder of the Thames and Severn Canal, rose at a level of about 330 feet above the sea (taking the Ordnance datum); and their volume was usually from 350 to 400 cubic feet per minute. He had never known them to afford less than 200 cubic feet per minute.

He did not understand whether the Author considered that these springs issued from the Oxford clay, or from the lower clays of the great oolite series.

Mr. **Clutterbuck** said, the water at Thames Head issued from the oolite, which was overlapped to the south by the Oxford clay; thus it received no additional water after it passed the junction of these strata. In September 1862 no water flowed from the head, as he had stated in the Paper.

Mr. **Taunton** proceeded to remark that, in his opinion, the Oxford clay had nothing to do with the out-throw of the Thames Head springs. From borings made in the locality many years ago, he believed that these springs issued from a bed of blue clay, probably the fuller's-earth, 27 feet in thickness, at Thames Head, and which was under the great oolite. It was in consequence of that alone, that these great springs were brought to the ground. Below this point, there were the Ewen Springs, the average yield of which might be taken at 150 cubic feet per minute; so that the whole of these springs gave, on an average, fully 500 cubic feet per minute. The River Churn, the next feeder, rose in the Cotswold Hills, at Seven Springs, near Cubberley, about 6 miles from Gloucester. The stream there was inconsiderable, but before it had passed the lias bed, the volume was increased. Gaugings which he took, in the autumn of 1849, just below Colesbourn, showed that the flow there was 420 feet per minute. After passing Colesbourn, the flow was diminished, some of the water being lost in passing the inferior oolite. The principal source of the River Coln was at Syreford, near Andoversford, and it also received a supply from a great number of springs which proceeded from the oolite. Gaugings taken at Fairford Bridge, on 22nd March, 1854, showed its volume to be 4,700 cubic feet per minute. He had calculated the drainage areas of these different gathering grounds, and found that of the Thames Head Springs and of Swill Brook to be 75 square miles, that of the Churn Valley was 64 square miles, and of the Coln 86 square miles, while that of the South Ampney Springs was 25 square miles, making a total area of 250 square miles. Now, a rainfall of 12 inches over that area would give a volume of upwards of 13,000 cubic feet per minute. It was stated, in the Paper, that at Wolvercot the summer flow was 8,120 cubic feet per minute, and the winter flow 17,224 cubic feet per minute, with a velocity in the former case of 58 feet per minute, and in the latter of 95 feet per minute. The mean of these quantities would be 12,672 cubic feet per minute, and assuming the drainage area at Wolvercot to be only 600 square miles, that result would be produced by 5 inches of rain, whereas the rainfall in that locality averaged about 30 inches a year. He therefore thought that the average flow of the river at Wolvercot must be much larger than had been stated, and that the sectional area of the river at that point must be greater than 140 square feet.

With regard to the navigation of the Thames, he thought there were other causes, than those generally assigned, for its present state. In reference to the remark attributed to the late Dr. Buckland, "that no lines of inland navigation could flourish, except they ran transversely to the lines of strata, as their variation ruled the products, and internal commerce of the country," he considered it empirical, and that the London clay traversing the greater part of the course had not much to do with the question, except so far as that it did not contain minerals. The interests on the Thames were distinct and separate. The right of the river belonged, in the first place, to the weir or millowner, and consequently the weir also. He had the right of pounding, and no boats could pass without he chose to pound, and he would not do so unless he was paid for it. At every weir there was a separate right. In addition there were the Thames Commissioners, who made the locks to pass the weirs. These different authorities must be made to accord before any real improvement could be effected; but there were so many weir and millowners' rights, and so many who took no interest in the navigation, that it was a difficult matter. With regard to the floods, the right of the weir or millowner extended to the fishing, and that right was most valuable in the early period of the flood. The eels began to pass just when the flood commenced to overspread the banks. It was at this time important to keep all the sluices down, except the one through which the eels were to pass. On some occasions, as the flood set in, as many as 4 cwt. of eels were caught. That was just the critical time when the flood should be let off; but the millowner had the right of pounding to what was called the old 'flash' mark, and that right he strictly preserved. He cared nothing for the flood, but he sought to catch as many eels as he could.

Mr. JOHN TAYLOR stated, that a survey of the River Churn, one of the principal tributaries of the Upper Thames, had been made under the direction of Mr. Simpson (Past President Inst. C.E.), in the dry period of the autumn of 1859. The gaugings of the volume of water, and other particulars then obtained, showed some extraordinary circumstances, with reference to the loss of water, by percolation, through the bed of the River and the Fish and Mill Ponds upon it. The flow from the Seven Wells, (the springs forming the source of the river in the Cotswold Hills) was ascertained to be 11 cubic feet per minute. At one-eighth of a mile below this point, the quantity had increased to 21 cubic feet per minute, and thence the increase continued, somewhat in proportion to the drainage area, as would be seen by the following Table:—

At ¼	mile below the springs the flow was	31	cubic feet per minute.
¾	" " "	61	"
1	" " "	73	"
2	" " "	105	"
2½	" " "	165	"
4¾	" " "	312	"
5½	(estimated as the maximum)	320	"

At this point, however, the volume of the river, instead of increasing, began to diminish, for,

At 6⅓	miles from the spring the flow had decreased to	290	cubic feet per minute.
7	" " "	235	"
7⅜	" " "	179	"
8⅛	" " "	113	"
8⅞	" " "	45	"
9¾	" " "	33	"
12½	" " "	30	"

and at 14¼ miles the quantity had actually become reduced to 10 cubic feet per minute, or less than the original flow of the Seven Wells. From thence to the junction of the river with the Thames at Cricklade, 22 miles from the source, the flow again gradually increased up to 110 cubic feet per minute. Thus, in a length of less than 8 miles of the course of this river, there was a measured loss of 300 cubic feet of water per minute, or 2,700,000 gallons per day. But even this was less than the actual loss, as, of course the stream would continue, under ordinary circumstances, to increase in proportion to the drainage ground, and allowing for this, the estimated flow at Cricklade ought to have been 450 cubic feet per minute, instead of being 110 cubic feet as gauged, thus showing a loss to the mills on the lower parts of the stream of 340 cubic feet per minute, or upwards of 3,000,000 gallons per day.

As to the geological character of the River Churn, the stream was derived, principally, from the drainage of a considerable area of the inferior oolite, and was thrown out by a fault at Seven Wells; the upheaval of the impervious beds of the upper lias clay preventing percolation in the direction of the dip of the strata. The stream then took its course through a valley of denudation, where the upper strata had been swept away in some convulsion of nature, forming in parts a deep narrow ravine, surrounded by the Cotswold Hills, which were composed chiefly of the porous and fractured rocks of the oolite. It thence passed over the impervious beds of the upper lias clay for nearly 6 miles, from the source at Severn Wells to Maresden Farm; next over the porous beds and fractured freestone of the inferior oolite for 3½ miles to a little below North Cerney Mill, by the Rendcomb fish-pond and the mill-ponds and courses of Rendcomb and North Cerney Mills; afterwards flowed over the impervious beds of clay known as fuller's-earth, continuing past Perrot's Brook and Trinity Mill to the mill-pond at Baunton, a distance of about 2¼ miles; and then it traversed the porous rubble freestone of the great oolite for 1 mile, by Stratton mill-pond. At this point commenced the tenacious clays of the forest marble formation, which, partly overlaid with the gravel and detritus of the oolite, passed under Cirencester, Barton, and New Mill Ponds to the head of Preston Mill; the only remaining porous strata being a short length at Preston and Seddington Mills, where the rubbly rock of the cornbrash formation outcropped in the bed of the stream. Thence the course of the river, from Seddington Mill to its confluence with the Thames at Cricklade, a distance of 7 miles, was entirely over the impervious beds of the Oxford clay. Such being the bed of the river, there was no doubt, the vast quantity of water which continually disappeared, percolated through the fissures and fractures of the rocky bed, and through the porous strata in the bottom of the mill and fish-ponds; and sinking below the impervious beds of fuller's-earth, never rose again in the valley of the Churn, but was completely lost to that river, and possibly even to the River Thames. Certain remedial works, chiefly such as puddling the bottoms of the ponds, were advised to be done, at a cost not exceeding £3,000, which would probably have prevented the loss of all this water; and it was estimated that this outlay would have resulted in a saving of nearly £1,400 a year in water-power.

Mr. S. C. HOMERSHAM said, it was now generally well understood, that rain falling upon different geological formation produced different results. Thus, upon chalk, the rain was immediately absorbed, even to the extent of 2 inches or 3 inches in depth in an hour, as sometimes happened over an area, say, of 100 square miles; whilst upon the primitive formations, it at once flowed off the ground, into the neighbouring valleys. He believed that the effect of draining clay lands directly into rivers, or into ditches that communicated with rivers, was, by removing the rain more rapidly, to increase the severity of the floods of the district. There were, however, hundreds of square miles of country, which for the last seventy or eighty years had been drained in a different way. For instance, where there was chalk, or other absorbent strata covered by clay 16, 18, or more feet in thickness, the drainage was effected by sinking in suitable situations, what were technically called dumb wells, from the surface through the clay for a few feet into the chalk, then filling the dumb wells with broken flints or stones, and conveying the water through drain tiles in the usual manner from the clay land into them. The effect was, that the rain, instead of flowing through various surface channels into the rivers and causing floods, was absorbed into the body of the chalk, and escaped underground into the sea. Floods in districts thus drained were much rarer than they used to be.

Allusion had been made to the gauge used by Mr. Dickinson, still incorrectly called a Dalton Gauge. On a former occasion, Mr. Homersham had stated[1] that the two were not alike, and he had shown in what respect they differed. Dr. Dalton's gauge was made with a view to register both the proportion of the rain which penetrated the ground, and also that which flowed off the surface. Accordingly, there was an overflow pipe, with a bottle, or vessel, to catch the water that passed off without entering the ground, as well as a vessel to catch the water sinking through the earth. The sum of these two quantities, deducted from the total rain-fall, would leave as a remainder the quantity that was evaporated. Now Mr. Dickinson avowedly employed only one vessel, or bottle, and this collected the water which percolated through the soil, but it gave no record of that which flowed off the surface. The consequence was that, for this and other reasons, the records of these gauges could not be depended upon; and for himself he did not hesitate to say, that having had occasion to make himself fully acquainted with them he placed no reliance upon the records of these gauges. It had been said that Mr. Dickinson was in the habit of regulating his contracts, as to the amount of paper he could manufacture, by the indications afforded by these gauges. Now Mr. Homersham doubted that, for at all Mr. Dickinson's mills in Hertfordshire, steam power, as well as water power, was applied for driving the machinery; the former being greater than the latter. Besides, there was an inexhaustible supply of water, from small wells, with bore-holes sunk in the bottom of each, at all these mills, from which, in the driest seasons, more water could be obtained than was ever required for the manufacture of paper.

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[1] *Vide* Minutes of Proceedings, Inst. C.E., vol. xiv., p. 82.

During the last twelve or fifteen years, numerous wells had been sunk into the chalk, for the purpose of obtaining water, without a single failure, so far as he was aware. At the present time the same thing was being done with the greatest success. Only a few years ago, the town of Hull was entirely supplied with water from the river: now it had sufficient for its whole supply from wells and bore-holes sunk into the chalk. Again, a large district of London was now supplied by the Kent Waterworks Company with from 4,000,000 to 5,000,000 gallons of water a day, obtained from wells sunk in the chalk, while for more than a century before, their whole supply had been taken from the River Ravensbourne. The wells not only yielded water abundantly, but the level of the water had not been lowered by the pumping. Therefore, he thought the Author was not justified in his views, as to the impolicy of sinking wells to procure large supplies of water from the chalk; and personally he had no confidence in any statements, with respect to the permanent lowering of the surface of the water in wells sunk in the chalk.

Mr. J. F. **Bateman** remarked that the facts and figures given in the Paper were not sufficiently numerous or minute to enable many deductions to be drawn from them. The area was not mentioned from which the water was collected, nor were there any particulars as to the quantity of water per acre, per minute, or during any other period of time. His acquaintance with the Thames was confined to the upper and lower ends; but of the main valley he had very little knowledge. He was, however, able to furnish some measurements of the flow of water in other streams in different parts of the country, showing the large amount of flood water that came off the land under certain circumstances in some districts, and the comparatively small amount which came from other districts under different circumstances. There was no doubt, that all the information that could be obtained, as to the amount of floods, the manner in which they rose, and the causes to which they were attributable, was valuable in an agricultural and engineering point of view. During the years 1833, 1856, and 1857, he had the means of ascertaining, with great accuracy, the quantity of water flowing off the ground, in a given time, by the River Medlock at Manchester. That river was a short stream, running through the city of Manchester, and draining only about 12,000 acres, principally of clay land. The maximum quantity of water passing off in those years was equal to a depth of 4 inches, 5 inches, and 6 inches respectively every twenty-four hours; that was, the volume of the floods when at their maximum was such, that those would have been the depths of water flowing from the ground had the floods continued at the same height for twenty-four hours consecutively. At the Manchester Waterworks, during the flood of February, 1852, which might be remembered as the time when the Bilberry Reservoir, near Holmfirth, in Yorkshire, was carried away, the water which came down from a district of 15,400 acres, was measured either in reservoirs, or through discharge pipes and gauges. The flow, when at the highest, was from 3,600 to 4,000 cubic feet per second, or 25 feet per second for each 100 acres, or 15 cubic feet per acre per minute, being at the rate of between 6 inches and 7 inches in twenty-four hours; and the mean flow during the same period was 1,520 cubic feet, or $2\frac{4}{10}$ths inches per second. In 1856, the quantity of flood water flowing into the Woodhead Reservoir, of the Manchester Waterworks, from an area of 7,000 acres, was equal to 2,100 cubic feet per second for seven hours forty minutes, or a depth of $2\frac{1}{4}$ inches, being at the rate of 7 inches in twenty-four hours. This quantity was equal to 18 cubic feet per acre per minute. In 1849, during the early progress of the work, a flood occurred at Woodhead which, at its maximum, amounted to 50 cubic feet per second for every 100 acres, or 30 feet per acre per minute, being at the rate of 12 inches in twenty-four hours. He had also some further measurements of the flood of May, 1862, at the Woodhead Reservoir, from the same district of 7,000 acres. For a period of two hours and a half, the flow was equal to $22\frac{1}{2}$ cubic feet per minute per acre; for seven hours it amounted to $14\frac{8}{10}$ths cubic feet per minute per acre, and for thirteen hours to $9\frac{1}{3}$rd cubic feet per minute.

At the Glasgow Waterworks, in October, 1854, the flood from Loch Lubnaig, Loch Voil, and Loch Doine, (the water surface of the lochs being about $\frac{1}{34}$th of the total drainage area of 44,600 acres,) was equal to 328,000 cubic feet per minute, or a depth of 3 inches flowing off in twenty-four hours, and $7\frac{1}{2}$ cubic feet per acre per minute. On the same day the volume of the flood flowing out of Loch Venachar, from a drainage area of 45,800 acres, but where the surface of the lochs was $\frac{1}{11}$th of the whole, the flood only amounted to 150,000 cubic feet per minute, not one half of that which flowed from Loch Lubnaig, from about the same area and the same rain-fall. This showed the regulating effect of large lakes, or sheets of water. The quantity stored in and discharged from Loch Katrine in twenty-four hours was equal to nearly 4 inches, while in two days it was equal to 6 inches of rain over the whole drainage area. The surface of Loch Katrine formed $\frac{1}{8}$th of the whole drainage ground of 23,300 acres.

In the River Clyde at Carstairs, in the winter of 1856-57, from a drainage area of 190,000 acres, the flow of water was equal to 20,000 cubic feet per second, or 6 feet per acre per minute; and of that quantity only 9,000 feet passed down the river channel, the remainder sweeping over the flooded land.

From a Table of the measured maximum quantities of water in various parts of the extensive valley of the Shannon, he would instance the measurement at Killaloe. Here the drainage was from a total acreage of 2,560,000, and the quantity of water in flood was 1,600,000 cubic feet per minute. The discharge of various large rivers into the basin of the Shannon, from actual measurement in flood, varied from 0·76 to 1·54 cubic foot per acre per minute, the latter being a maximum. That contrasted very strikingly with the quantities he had given from mountain districts in England and Scotland, where they amounted to 6, 7½, 9⅓, 15, 18, and in one case 30 cubic feet per acre per minute. He gave these measurements for the purpose of drawing attention to the great differences which existed, in order that one river might not be taken as a guide for calculations upon another, except when the circumstances were similar.

Mr. **Frederick Braithwaite** remarked that, from the statements which had been made, it was evident a large quantity of the flood water which was supposed to fall into the Thames, did not reach the tidal part of the river below Teddington Lock. Of late years, in dry seasons, there had at times been so little water flowing over the lock, that the salt water had nearly reached as far up as Hammersmith. Moreover it was stated, that from ninety to one hundred million gallons of water per day were now being taken from the river above Teddington Lock for the supply of London; and as, by the main outfall intercepting sewers, the whole of that quantity, together with the rain falling on the area so drained, would be conveyed beyond the metropolis, to Barking Creek and to Erith, it was important to ascertain, what would be the probable effect of the abstraction of so large a body of fresh water from the tidal part of the river. It was manifest that it must lead to the intrusion of a still larger quantity of salt water. Dr. Letheby had recently stated,[1] that the mixture of a large proportion of salt water with the fresh water was likely to be attended with unhealthy results, as noxious exhalations would arise from the mud on the banks, in dry weather.

The Author had referred to the subject of evaporation, both from the earth and from a surface of water, stating that in the latter case the amount was very small; and citing in proof of this opinion, the case of two vessels both filled with water, but in one of which a brick was placed, and that the evaporation was much greater in the vessel containing the brick than in the other. Now, all evidence went to show, that the amount of evaporation from water was 30 inches per annum. He could readily understand, that if a porous substance was put into a vessel of water, the surface of evaporation was increased, and also the amount of capillary attraction which assisted the evaporation.

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[1] *Vide* a letter in "The Times," March 16, 1863, p. 10, headed "The Water of the Thames."

Some observations had been made, in which he did not concur, with regard to Mr. Dickinson's rain-gauge. He thought that the overflow pipe of the rain-gauge had nothing to do with evaporation; and that the absorption was dependent upon the nature of the soil. There were some descriptions of soil which would variously absorb from 20 per cent. up even to 60 per cent.; therefore it was unphilosophical to generalise, nor could it be done with any approach to accuracy.

Mr. R. B. Grantham said, the map which had been prepared for the Salmon Fisheries Committee, by Colonel Sir Henry James R.E. (Assoc. Inst., C.E.), a copy of which he then presented to the Institution, gave some interesting details of the water-shed of most of the principal rivers in England, amongst the rest, of the Thames, and was a most important document for all who were interested in the drainage of the country. The areas of the catchment drainage of two hundred and four rivers and their length were enumerated, from which he had extracted the following particulars relating to a few of the principal rivers:—

	Area in Square Miles.	Length in Miles.
Thames	5,162	201¼
Ouse (Yorkshire)	4,207	59½
Trent	3,543	167½
Severn	4,437	178
Nen	1,055	99
Great Ouse (Cambridgeshire). .	2,894	156¼
Mersey	1,706	68
Tyne	1,053	35
Witham	1,052	89
Medway	997	69
Humber	1,229	37
Wye (Herefordshire) . . .	1,655	148

It would be extremely useful if this inquiry could be extended, so as to include the catchment basin of the minor rivers.

The Valley of the Upper Thames did not appear, from the description, to differ materially from the formation of the valleys of other rivers, except from its magnitude. It consisted of a series of large and flat areas, at places throttled by the hills, and by the undulations of the country closing upon and narrowing the valleys. It was at those places, he believed, where the gorges occurred, that the greatest improvements might be made, and to which the attention of Engineers should be directed, to draw off the floods. But the Paper, though interesting in a geological point of view, as showing Engineers the sources whence water was derived, gave no suggestions as to the mode of treating the Valley of the Thames, so as to improve its drainage.

Mr. **Gravatt** said, he should not have been induced to make any remark, had it not been stated, that the present condition of the Thames Navigation and Drainage rather implied a low state of Engineering skill in such matters. He had had to do with Navigations, Mills and Drainage for many years; amongst others with the Calder and Hebble navigation, and he was old enough to have actually constructed a Canal, called the Longport navigation. The Calder and Hebble works were originally laid out by Smeaton for a 3-feet navigation; and, as an instance of Smeaton's foresight, when the depth had to be increased to 5 feet, there was only one lock-cill that had to be altered, and that lock, Mr. Gravatt found, had been built by another Engineer, to avoid a local opposition. The real difficulties were not at all of an engineering character, but they arose from the supposed difference of interests, between Navigation Proprietors, Drainage Commissioners, and Millowners. Where these parties agreed, the Engineering difficulties almost vanished. As one instance out of many, already known to several Engineers, he mentioned that when the proprietors of the Calder and Hebble Navigation bought the Mills, there was no further difficulty. The Navigation proprietors, who had been before subject to continual lawsuits, completed their works, at a moderate expense, and the rents of the Mills actually increased. The power of half ruining a navigation, or of flooding large tracts of land, for the sake of a few hundredweights of eels, was a legal power possessed by many persons; but the difficulties that arose from such a source could not seriously be called engineering difficulties. He thought sufficient had been said to show, that the present state of the Upper Thames was not to be attributed to any fault of Engineers, or their works.

Mr. **Frederick King** said, as a resident, for upwards of forty years, upon the banks of the Upper Thames, he had witnessed the most prosperous trade in the navigation, the many abuses practised upon the stream for the monopoly and misuse of the waters, and subsequently its decline and fall. For more than twenty-five years he had endeavoured to suggest remedies for the evils existing in this, the most fertile valley, and perhaps the most abused in England. He had been engaged as the valuer under several enclosures of meadow districts, between Oxford and Lechlade, subsequently followed in the same district by the late Mr. Woolley, one of the Enclosure Commissioners, and since by Mr. Bryan Wood. All had encountered the same difficulties, that whilst cuttings and drains could be made, no proper outfall could be obtained, for the system of economising the water in former days was such, that the whole valley was submerged, and the land a perfect swamp,—the habitation of wild-fowls. This was considered, though erroneously, to be necessary by many, when the only means for the transport of coal, corn, timber, slate, stone and heavy goods was by navigable streams, and more recently by canals, and when water was almost the only motive power for grinding corn, and working the rude machinery of bygone days. He feared that the way in which Dr. Acland had taken up this subject was calculated still further to complicate it, by not keeping it separate from that of the disposition of the Sewage of Towns, a question which must have its issue first in London, when the main drainage works were completed.

The Paper was interesting, as it professed to show the source whence the water was derived which had to be dealt with. He believed that both in an agricultural and in a sanitary point of view, nothing more was required than the perfect drainage of the now water-logged valleys, so as to convert the swamps which now disgraced them into fertile vales, by which the health of the inhabitants of the numerous towns and villages situated on the course of all navigable rivers would also be improved. The plan formerly adopted, for securing the largest supply of water for navigation purposes, was to place a lock, or weir, immediately below a great outlet of land drainage, or of tributary streams running into the main river, by which, when the locks, or weirs were closed, instead of filling the river, (itself sufficient for all the purposes of navigation, if properly fed,) thousands of acres of rich land were unnecessarily submerged, or partially so. It was a fact that at the present time, not one boat passed annually down the Upper Thames from Lechlade to Oxford, and yet the water was still impounded. Even in hay-time, in dry summers, the water was dammed up to a depth of 3 inches to 6 inches amongst the hay, the herbage being water-plants, instead of nutritious grasses fit for animal sustenance. This occurred now, he believed twice a week, when the water was impounded for the purpose of sending down the unnecessary semi-weekly 'flashes.' If the river were made a perfect canal, and the land drainage was allowed to fall into the main stream immediately below a lock, mill, or weir, as the case might be, instead of immediately above it, this state of things would be remedied. Any increase in the tail water, tending to diminish the motive power, would be compensated by the head-water being raised in a corresponding degree, by the admission of the land drainage into the river at a higher level.

The observations in the Paper went to show that the great evil in the level of the Upper Thames was occasioned by the narrow gorge at Sandford, where the coralline, or coral rag, overlapped the Oxford clay. One of the consequences above Oxford of this great natural obstruction was that the levels of Wolvercot Mill, King's Weir, and Wytham Mill Streams, had all been raised, within the time named, by the improper addition of new cills on the old ones, by which many acres of land had been flooded nearly a foot deep. This was only one of many similar abuses. Thus the damming up of Shire Lake Ditch at the top of Godstow, and of Swift's Ditch at the bottom of Godstow Liberty, had ruined Port Meadow, improved Binsey, and swamped Oxford. The treatment of all navigable valleys was a national question, affecting the production of food for cattle, and consequently of food for the people, and this could only be properly done by the application of Parliamentary Powers, the preliminaries of which in his opinion were, forming each valley into an elective drainage district, or districts, giving one-tenth of the proprietors of any area requiring a combined system of drainage, power to apply to the Enclosure Commissioners, to constitute such lands into a separate elective drainage district, with a saving clause as to the consent of existing Commissioners of Sewers, Town Councils, Local Boards of Health, or Improvement Commissioners. Upon receiving this Petition, the Commissioners should appoint an Inspector to make local inquiry as to the propriety of the boundaries of the areas proposed to be drained, &c. In the event of the proprietors of one-third of the land comprised within the area dissenting, within a given time, the Commissioners should dismiss the Petition. He suggested that the area to be dealt with was the alluvial strata of the whole valley, as laid down on the Geological Maps of the Ordnance Survey.

The Rev. J. C. CLUTTERBUCK said, in reply upon the discussion, that though he had had access to much information from landowners, he found it impossible to ascertain the extent of agricultural drainage, or to make any calculation of the drainage area of each tributary stream. It must be remembered that the whole area, 1,500 square miles, comprised every variety of soil, involving most complicated geological conditions. Thus, the water was thrown to the surface, in some districts, by the underlying lias clays, in others by the fuller's-earth, in another by the clay beds of the forest marble, and then from the extended surfaces of the Oxford, Kimmeridge, and gault clays. He had described the geological condition of districts drained by each tributary, and must refer to the Paper for all the information he could give. The accuracy of the gaugings had been questioned, the minimum flow at Wolvercot being deemed too small. Certain gaugings at other points were brought forward; but to show that these latter could not be relied on, it was only necessary to refer to the case of the Churn, a very considerable tributary, which decreased in its course from 320 cubic feet to 110 cubic feet per minute. It had also been stated that the Thames Head seldom yielded any water to the river. Averages of rain-fall afforded no guide to the minimum flow of rivers, which could only be ascertained by actual observation. Personally he had great confidence in the gaugings at Wolvercot, as they were taken by a man of experience and an accurate observer. Mr. Treacher, the late surveyor of the Thames, had informed him that, in 1855, the perennial flow in the Thames was so much reduced, owing to the rain-fall in the previous eighteen months only amounting to the yearly average, that all the flood-gates at the Pangbourn Lock were opened at one time, a fact without example in his long experience. With regard to the capacity of the river for the discharge of flood-water, when the river at Clifton Hampden, between Abingdon and Wallingford, ran 'flash' high, the flood-gates at the lock being shut, the velocity was 134 feet, and the discharge 51,000 cubic feet per minute. In January, 1863, when the flood attained its height, on the flood-gates below being drawn, the velocity was increased to 265 feet, and the discharge to 182,000 cubic feet per minute, though the area occupied by the flood was only doubled. He believed that Mr. Bryan Wood's system of confining the flood by low banks would be generally adopted, in executing the so-much needed improvements of the Thames Valley.

With regard to the objections to the experiments on evaporation, experience would show, that the increase of winter evaporation from drained soils would tend to diminish winter floods. He believed that the amount of evaporation from a surface of water, or the wet surface of the soil, was over-estimated. In corroboration he could refer to the dew-ponds on the downs, which, when once filled, were never without water: he repeated his belief that the extension of agricultural drainage would tend to decrease floods. As to the remark that in Dalton's gauge no account was taken of the overflow from the surface of the soil, on looking to the daily records of that gauge, he observed that when rain commenced, only 1 inch out of 1½ inch was recorded, showing that the ½ inch went to replace the previous evaporation. If the rain continued, as in January, 1863, the whole of the next inch would percolate to the lower receptacle, and there would be no waste by overflow. As to what had been said about the water supply to be obtained from the chalk, it should be remembered that the London wells alone had been alluded to in the paper; and he believed that the decrease in the level of the water in many of the wells of the large breweries in London confirmed his view. At the same time he could confidently affirm, that many towns depending for their supply of water from chalk wells might draw too heavily upon the quantity of water at command.

Mr. HAWKSHAW, President in thanking the Author for his useful communication, which he regretted not to have heard read, would only observe, that as far as he had considered the matter he thought it probable, that extensive agricultural drainage might have the effect of decreasing floods.

At this Meeting it was resolved unanimously:—

"That in consequence of the marriage of H.R.H. the Prince of Wales having been fixed for Tuesday, the 10th of March, there should not be any Meeting of the Institution on the evening of that day."

March 17, 1863.

JOHN HAWKSHAW, President,
in the Chair.

The discussion upon the Paper No. 1,074, on "The Perennial and Flood Waters of the Upper Thames," by the Rev. J. C. CLUTTERBUCK, occupied the whole evening to the exclusion of any other subject.

March 24, 1863.

JOHN HAWKSHAW, President, in the Chair.

No. 1,075.—"Description of the Lydgate and of the Buckhorn Weston Railway Tunnels." By JAMES GRANT FRASER, M. Inst. C.E.

IN introducing a Paper on so important a subject as Railway Tunnels, the Author feels considerable diffidence, on account of their long existence, and the extensive knowledge already possessed by Engineers relative to their construction. Yet the paucity of recorded information of a practical character, in the Minutes of Proceedings of the Institution, or elsewhere, on this interesting branch of Civil Engineering, would furnish an excuse, if one was required, for hazarding a Paper on such well-known structures.

The late Mr. R. Stephenson, M.P., in his address as President, delivered January 8th, 1856, stated,[1] that nearly 70 miles of tunnelling had then been formed in Great Britain. It may not, therefore, be inaccurate to assume 80 miles as representing the length of tunnels now daily traversed by railway trains in the United Kingdom; and supposing that they have cost, on an average, £45 per lineal yard, the capital expended in their construction will have amounted to the enormous sum of about six and a half millions sterling. Up to the present time, communications referring to a length of only 3 miles of tunnels, constructed at a cost of about one-quarter of a million, or one twenty-sixth of the total expenditure, have been read at the Institution, so that it is manifest this class of work has been inadequately chronicled. Each tunnel has its own peculiar history; the variety of strata, the springs of water, &c. all require different treatment, and have demanded a greater amount of forethought, and probably occasioned more anxiety to the Engineers, than any other description of work. Kilsby, Box, Woodhead, and many other tunnels, remain as bold illustrations of conquered difficulties, but their histories are still untold. If particulars of all important Engineering works were, either during their construction, or immediately after their completion, transmitted to the Institution, for the information of the members, more effectual remedies might in many cases be practised, with advantage to public economy.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xv., p. 125.

In selecting instances for this Paper, the Author will confine himself to descriptions of two tunnels that have been executed under his immediate superintendence, upon lines of which Messrs. Locke and Errington were the Engineers-in-chief.

The Oldham branch of the London and North-Western Railway commenced by a junction with the main line at the Greenfield Station, and terminated at the Oldham Station of the Lancashire and Yorkshire Railway. Its length was 3 miles 64 chains, and it was constructed at a cost of £35,000 per mile, exclusive of the purchase of land.

The Lydgate Tunnel on this branch was driven through the coal measures. The accompanying longitudinal section (Plate 8, Fig. 1), prepared from measurements taken during the progress of the works, illustrates the geological details. Faults are common in this formation; sometimes severing it in the line of the dip, at other times in the line of the bearing. Several of these distortions were met with in this work. Plate 8, Fig. 2, exhibits the singular manner in which one of these presented itself, one half of the tunnel being in strong shale and rock in veins, whilst the other half was in a mass of wet and loose shale. The lengths of the different strata cut through were,—

Clay and loose shale	210	lineal yards.
Strong shale	335	„
Strong shale, interspersed with bands of rock	474	„
Rock, with veins of shale	135	„
Rock	130	„
Limestone	13	„
Fire-clay	30	„
Coal	5	„
Total length of the tunnel . . .	1,332	„

Five shafts were required for completing the tunnel within the time specified: their total depth amounted to $289\frac{1}{3}$ lineal yards, and the average rate of sinking each was 11 yards per month. Four were left for permanent ventilation, the space between them being about 230 yards. No. 1^a had formerly been a colliery shaft, and had not been used for many years. It was reopened by the Contractor, and from it a cross-heading was driven into the tunnel, the centre of which was 40 feet distant. Great care had to be exercised in fixing the centres through the portion lined from this heading (245 lineal yards), as part was on a curve, and part on a straight line. Fortunately perfect accuracy was secured. The proximity of the shafts checked much inconvenience arising from foul air. Where it occurred, fans were fixed on the surface, and a volume of air was forced down, and conveyed through pipes, fastened along the tunnel. A sufficient supply was thus transmitted, to enable the miners to form a junction between the headings. In the neighbourhood of the old coal-workings, which ran across the tunnel, a considerable amount of choke-damp was met with. To overcome its effects, a bore-hole was sunk from the surface, and was lined with an iron pipe, down which fresh air was forced.

The sinking of the shafts was carried on in the usual manner, by excavating through soft material, and drilling and blasting through rock. After attaining the average depth of 60 feet, the material was raised by engine power. The four permanent shafts were lined with 9-inch brickwork, or about 12 inches of masonry, except where in rock. They were finished at the soffit of the tunnel with ashlar curbs about 2 feet 3 inches deep. Where water penetrated, iron shields, with a gutter round the edge, were suspended, and the water was conveyed by a pipe, down the side of the tunnel, into the regular channels. The shafts were carried up 12 feet above the surface of the ground, and were completed with an ashlar coping. They were circular in plan, their diameter being 9 feet in the clear; this size was, however, found to be insufficient to allow of the skips ascending and descending simultaneously, which occasionally caused a short delay. A slight increase in the diameter would have prevented this. A steam engine of 9 H.P. was fixed at shaft No. 1^a, and locomotive engines between shafts Nos. 1 and 2, and shafts Nos. 3 and 4, each locomotive working two shafts.

The following table gives the depths of the shafts and the rate of sinking, which averaged 11 lineal yards per month:—

No. of Shaft.	Commenced.	Completed.	Depth to the Formation Level.	Rate per Month.
			Lineal Yards.	Lineal Yards.
1^a	August, 1854 .	October, 1854	27⅓	. .
1	Ditto . . .	November, 1854	53⅓	13
2	Ditto . . .	February, 1855	80	13
3	Ditto . . .	February, 1855	75⅔	12½
4	Ditto . . .	January, 1855	53	5
		Total . .	289⅓	43½

With the exception of the faces worked from each cutting, and amounting to 141 lineal yards, through which a bottom heading was driven, the tunnel was 'mined' by a top heading, 6½ feet by 4½ feet, being first made. The shafts furnished ten faces, and 1,191 lineal yards out of the total length, were worked from them, each face averaging 17·26 lineal yards per month. The open ends gave four faces, and both equalled 9 lineal yards per month. The lengths mined from the different shafts are given in the following table:—

No. of Shaft.	Lengths Driven.		Total.	Time occupied.	Rate per Month.
	East.	West.			
	Lineal Yards.	Lineal Yards.	Lineal Yards.		Lin. Yards.
1^a	138	107	245	1854, Oct., to 1856, March	15
1	157	126	283	„ Dec., „	19
2	100	96	196	1855, March, „	16
3	95	108	203	„ „ „	17
4	119	145	264	„ Feb., „	19
Faces	95	46	141	„ Oct., „	9
		Total .	1,332	. . . .	95

There was no peculiarity in the mode of excavating in this case, rock and strong shale being blasted by means of powder, and the softer material, clay and loose shale, being displaced by the pick-axe. When the top heading had been driven for the full distance of each length, the crown was protected by poling boards and bars of larch, which description of wood is almost universally adopted for bars, on account of its strength, combined with its elasticity. After the ground was secured, it was widened out to suit the shape of the tunnel, and the same description of timbering was continued to 9 feet, or 10 feet above the formation level; the distance between the bars being gradually increased. The earth was removed in iron skips, (capable of holding half a cubic yard each), which were placed on light 'trollies,' and were pushed along tramways laid between the work and the shafts. They were there raised by engine power, and tipped on the spoil-banks on the surface of the ground. The contract price for this, without distinction, was 4*s.* 6*d.* per cubic yard, including all the timbering.

Where expedition is an important element in the construction of tunnels, the common mode of sinking shafts and multiplying the number of faces presents many advantages; and it is doubtful whether mechanical contrivances will ever bear comparison with manual labour, when it is possible to get several points simultaneously under the miners' operations. Another system, occasionally followed, is driving a heading near the rail, or formation level, and at intervals forming a 'break-up.' This becomes, in fact, the shaft of the former method, and presents the working faces. But it can be easily understood, that one opening for a number of men and a quantity of materials is not so successful in rapidity, as the system of sinking shafts, each of which affords a free channel for supplying all the requirements of the labourers. Again, no progress can be made with this heading, until the cuttings, or their gullets, are run up to the faces of the tunnel, and there are frequently obstacles to this being done, as the gradients do not always admit of the drainage being preserved. A bottom heading likewise necessitates a much longer exposure of the sides to the action of the atmosphere, which, in clays and marls, loosens the ground, causing weight to follow, and in rock opens the fissures. As a rule, in tunnel construction the masons, or bricklayers, should commence lining the ground prepared by the miners, as soon as possible after it is ready.

The lengths mined, before lining with masonry, varied according to the nature of the ground; averaging in loose shale 3 lineal yards, through strong shale 5 yards, and through rock 8 yards, and in some instances 10 yards. The prices paid to the miners varied from £8 to £18 per lineal yard, according to the material; nearly one-half of the total length of the tunnel amounting to £12 per lineal yard, or less.

The centres consisted of skeleton ribs, placed about 1¼ yard apart. At the leading end two sets were fixed close together for greater security. This description of centering is very suitable for this kind of work, on account of its lightness, its non-liability to be injured by the masses of rock scattered about after blasting, and the facility with which it can be readjusted to the true contour line when distorted in the work. The price allowed for setting the centres was 8*s*. per rib.

The masonry used in building the side walls was coursed rubble, the beds of the stones being punched with a hammer. The footings were not less than 18 inches below the formation level, and the walls were carried 7 feet 3 inches above the level of the rails; the tunnel being 24 feet 6 inches wide at that point. The arch for about 632 lineal yards was turned with fitted rubble, but from the scarcity of good bedded stone, 700 lineal yards of arching had to be built with brickwork. The contract price throughout for masonry was 20*s*. per cubic yard. The time the masons and labourers were allowed for building, with the cost, was as follows:—

Side walls, 2 feet 6 inches thick, and 12 feet in length,					
4 masons, 1¾ shifts of 8 hours	= 7	at 5*s*. 6*d*.	£1	18	6
9 labourers ,, ,,	=15¾	at 3*s*. 6*d*.	2	15	1½
Arch, 2 feet thick, and 12 feet in length,					
4 masons, 3 shifts	=12				
2 ditto, extra, for key, 1 shift	= 2	14 at 5*s*. 6*d*.	3	17	0
11 labourers, 3 shifts	=33				
3 ditto, for key, 1 shift	= 3	36 at 3*s*. 6*d*.	6	6	0
			£14	16	7½

or about 4*s*. 9*d*. per cubic yard.

The mortar was composed of barrow stone lime, mixed with coal ashes, in the proportion of 2 to 1, ground by heavy iron rollers, and used fresh. Its setting power was most satisfactory.

Where much weight showed itself, by the bars either sagging, or springing, the crown bars were built in, and the spaces between, called the 'mid-feathers,' were filled with brickwork. The ordinary practice is to draw the bars after the arch is keyed, and then to pun in earth, filling the mid-feathers with masonry. One of the most important features in tunnel building is the prevention of any motion in the ground, as when it occurs there is always great expense in overcoming it, and many failures may be traced to this as an originating cause. In cases where water was met with over the crown of the arch, the tunnel was covered with zinc, terminating in a gutter to convey the water to some convenient point, where a pipe was built through the masonry, for its discharge into the proper drains.

There was considerable variation in the thickness of the masonry. In shale, the strength of work was as shown in Plate 8, Fig. 3; whilst in rock, the section Plate 8, Fig. 4, was adopted. The following table gives the lengths of each thickness built:

Length.	Thickness.		Earthwork, per Lineal Yard.	Masonry, per Lineal Yard.	Total Masonry.
	Side Walls.	Arch.			
Lineal yards.	Ft. in.	Ft. in.	Cubic yards.	Cubic yards.	Cubic yards.
10	3 6	2 6	84	20	200
30	2 9	2 6	82	18¼	547
16	2 6	2 6	81	17½	280
30	2 6	2 3	79½	16⅓	490
120	2 6	2 0	78	15¾	1,890
119	2 0	2 0	76	14½	1,725
62	2 0	1 9	74	13⅓	827
24	2 0	1 6	72½	11¾	282
500	1 9	1 6	71	11⅓	5,667
421	1 6	1 6	70	10¾	4,526
1,332	..	..	..	..	16,434

The average quantity of masonry per lineal yard was 12⅓ cubic yards.

The total length of the tunnel was 1,332 lineal yards. The first length was keyed in on the 27th October, 1854, and the last was finished on the 21st March, 1856, a period of seventeen months, or about 80 lineal yards per month, irrespective of the shaft-sinking. The tunnel was on a straight line for 47½ chains in length, and for 13 chains on a curve of 74 chains radius. The width of the tunnel was 25 feet, and was so continued to 3 feet above the level of the rails. The height to the soffit was 20 feet above the level of the rails, and the footings averaged 3 feet 6 inches below the rails. For 7 feet on each side of the crown the radius of the arch was 10 feet 6 inches, then for 9 feet the radius was 14 feet 8 inches, and for the succeeding length of 7 feet 7 inches, the radius was 26 feet 6 inches. The drainage was carried down channels formed of dry stone pitching along the face of the side walls. The ballast was composed of broken stone, 2 inches diameter, for 1 foot in depth, covered with ashes to the level of the rails.

The contract price for the tunnel through rock was £26 per lineal yard, and through shale £35. 16*s*. per lineal yard, the average price being £30 per lineal yard.

The Buckhorn Weston Tunnel on the Salisbury and Yeovil Railway was constructed through Kimmeridge clay, intersected with veins of loose rubbly rock, as shown in the geological section. (Plate 8, Fig. 5.) These veins acted as conduits for a large quantity of water, which flowed into the tunnel, for nearly one-half its length. The vein that principally affected the work is marked 'loose rock and water' in the section. The main difficulty to be overcome was the evil effects arising from this volume of water, amounting to about 90 gallons per minute, which being confined to the crown, instead of a general 'shedding,' was a source of expense as well as of delay. It was eventually remedied by driving a heading, 5 feet by 5 feet, for 200 yards in length, above the tunnel, and about 10 yards beyond it. A pipe 12 inches in diameter was laid in this; the remainder being filled up with loose stone. The water was thus intercepted, and carried away from the work. This heading is shown in the longitudinal section (Plate 8, Fig. 5).

It was originally intended, in executing this tunnel, only to sink two shafts, and to form a bottom heading for waggons from the cutting at the west end, the gradient falling in that direction, so that drainage could have been obtained. This heading was driven for 200 lineal yards, when the action of the atmosphere caused the sides to bulge so much that double timbering had to be resorted to. As this failed to check the swelling, the plan was abandoned, and a smaller heading was substituted. The waggons were consequently prevented from entering the tunnel, and three additional shafts, making five in all, had to be sunk. As they were not intended to be permanent, the sides only were timbered, but in a very strong manner, on account of the treacherous nature of the ground. These shafts were 8 feet square in the clear, and their cost amounted to £1. 10*s*. per lineal yard of tunnel. The earth was raised by horse gins, kept in constant operation. The average price for mining and tipping was 4*s*. 6*d*.

per cubic yard. The lengths mined from the different shafts are given in the succeeding table:

No. of Shaft.	Lengths driven.		Total.	Time Occupied.	Rate per Month.
	East.	West.			
	Lineal Yards.	Lineal Yards.	Lineal Yards.		Lin. Yards.
1	63	45	108	1858, Oct., to 1860, Jan.	7½
2	64	88	152	„ „ „ Feb.	9½
2^{a}	29	29	58	1859, July, to „ Jan.	10½
3	89	106	195	1858, Sept., to „ Feb.	12
4	70	62	132	1859, July, to „ „	16½
Break-up	..	..	73	„ „ „ „	10½
Face	..	..	21	„ Oct., to 1859, Dec.	10½
		Total .	739		77

The mining was conducted in a similar manner to that of the Lydgate Tunnel, a top heading being first driven from each shaft. The shafts furnished ten faces, and 645 lineal yards were worked from them, averaging 56 lineal yards per month. The 'break-up' and face gave three additional faces, and 94 lineal yards were mined from them, equal to 10½ lineal yards per month. This, under the circumstances, is a favourable return. The lengths mined, before lining with masonry, ranged from 3½ lineal yards in heavy ground, to 5 lineal yards in favourable strata. The average cost of mining per lineal yard was £30, exclusive of the shafts.

The bars were of larch of large scantling, the crown bars being 18 inches diameter, and fixed about 18 inches apart (Plate 8, Fig. 6). The centres were strongly braced, each rib containing 35 cubic feet of timber, and 285 lbs. of wrought iron in bolts and straps. The centres were fixed about 1¼ yard apart, and the cost of setting came to 6*s*. per lineal yard of tunnel.

As side pressure was anticipated at the commencement of the work, the first ten lengths were built with an invert, which contained 4 cubic yards of brickwork per lineal yard (Plate 8, Fig. 7). Further experience, however, and a more accurate knowledge of the material, justified the abandonment of the invert. The pressure at the crown of the tunnel, occasioned by the water, rendered it necessary to construct a length of 390 lineal yards, with seven rings of brickwork, or 2 feet 8 inches in thickness. The remaining length of 350 lineal yards was favourable, the water-line having dipped gradually, as is shown in the longitudinal section. Through this distance the section, Plate 8, Fig. 6, was adopted. The tunnel was built throughout of brickwork; upwards of six millions of bricks being used. The neighbourhood was totally unprovided with sharp sand, and as a substitute, burnt clay, fine sand, (the material of the locality) and broken bricks, were ground together, and mixed with Bridgewater hydraulic lime, in the proportion of 2 to 1. The result was perfectly successful. Great caution was exercised in packing behind the brickwork, to prevent subsequent settlement of the surrounding ground. Many of the bars were left in, and the spaces between were filled solid with brickwork. Throughout the heavy ground three bars in each length were on an average bricked in.

After the completion of the work, a large quantity of water continued to percolate, which was conveyed by pipes into the regular channels. The discharge of water was gauged at the completion of the works, when it was not found to have abated, since the time of its being tapped upwards of eighteen months previously.

The following table gives the lengths of each thickness built:

Length.	Thickness of Work.	Earthwork, per Lineal Yard.	Masonry, per Lineal Yard.	Total Masonry.
Lineal yards.	Ft. in.	Cubic yards.	Cubic yards.	Cubic yards.
4	3 5	110	27·25	109
41⅓	2 8 with invert.	95	24·38	1,008
335⅔	2 8	85	20·56	6,903
178⅓	2 3	80	18·22	3,250
178½	2 0	77	14·88	2,657
737⅚	..	..	..	13,927

The average quantity of earthwork per lineal yard was 80 cubic yards, and of brickwork 20 cubic yards. The total length of the tunnel was 739 lineal yards. The first length was keyed in on 6th October, 1858, and the last on the 17th February, 1860, giving sixteen months for completing this work. The width of the tunnel was 24 feet 6 inches at the level of the rails, widened out to 25 feet at 3 feet above. The height was 20 feet above the rails. The crown of the arch in this case was more pointed than in the Lydgate Tunnel, the radius being 9 feet 3 inches for 5 feet on each side of the centre; then a radius of 14 feet 3 inches for 7 feet 6 inches, and for the remaining length of 11 feet 9 inches the radius was 21 feet 9 inches.

The total cost of this tunnel was £53,000, or £72 per lineal yard, of which detailed particulars of every item are subjoined:—

Description.	Total Cost.	Cost per Lineal yard of Tunnel.			Cost per Cubic yard.	
	£.	£.	s.	d.	s.	d.
Mining and tipping	13,300	18	0	0	4	6
Headings and shafts	3,070	4	5	0	..	
Timber	3.400	4	15	0	..	
Iron and steel	2,250	3	0	0	..	
Powder and grease	1,040	1	9	0	0	4¼
Horsework	4,300	5	16	0	..	
Bricks, coal, and sand	13,650	18	10	0	18	6
Lime and sand	1,732	2	7	0	2	4
Bricklaying	6,003	8	0	0	8	0
Setting centres	225	0	6	0	0	3½
Temporary roads and buildings	1,095	1	10	0	..	
Management and plant	2,650	3	10	0	5 per cent.	
Faces and drain	400	0	10	0	..	
Total cost	53,115	71	18	0	..	

In conclusion, it is satisfactory to be able to state that in neither of these tunnels has any failure been perceptible. The Author trusts that this description may be the means of eliciting from other Members of the Institution further information on this subject.

The Paper is illustrated by three Drawings, giving longitudinal sections of the strata passed through, as well as cross sections of the tunnels at different points, from which Plate 8 has been compiled.

[Mr. FRASER

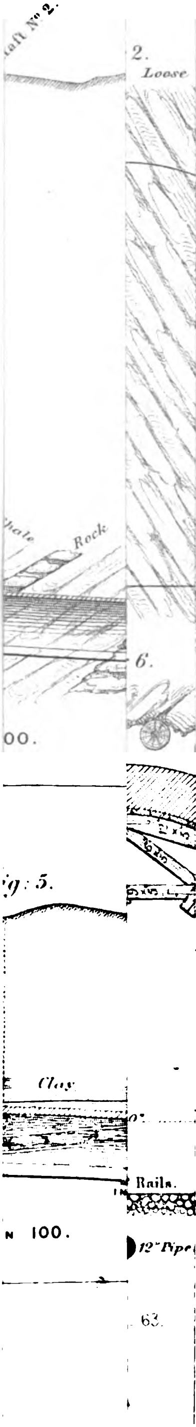
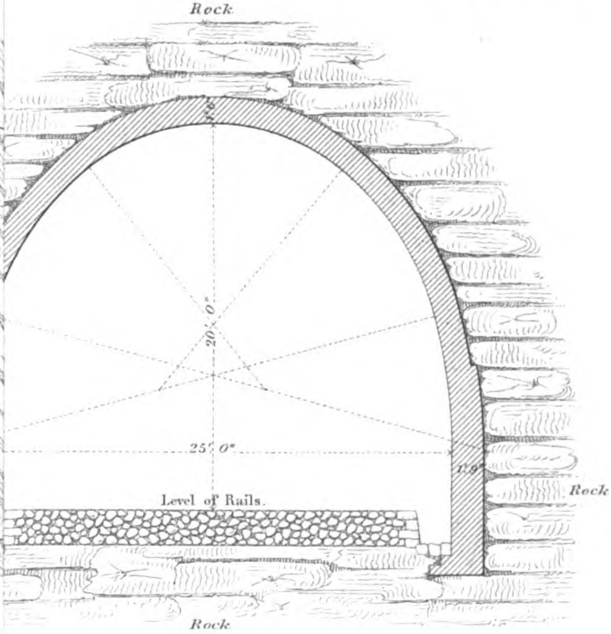

aft No 2.
2.
Loose
hale
Rock
6.
00.
ig: 5.
Clay
0.
Rails.
N 100.
12" Pipe
63.

Fig: 4.


Rock
1.6
20. 0.
25. 0.
1.9
Level of Rails.
Rock
Rock

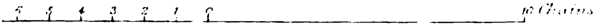
Scale for Figs 2. 3. 4. 6 and 7.

10 Feet = 1 inch.

0
10
20
30 Feet.

Scales for Figs 1 and 5.

Longitudinal: 6 Chains = 1 inch.


6
5
4
3
2
1
0
10 Chains

Vertical: 80 Feet = 1 inch.

30
20
10
0
100
200 Feet

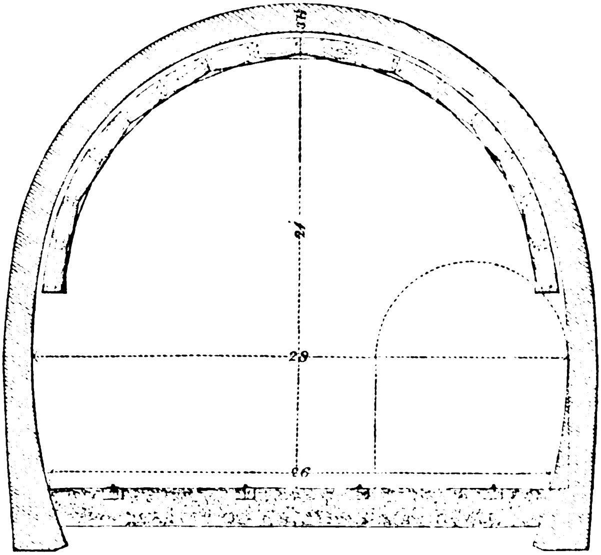
KELL BRO. LITHRS CASTLE ST HOLBORN

Mr. **Fraser** thought the following summary of the cost of railway tunnels, constructed under the direction of Messrs. Locke and Errington, might be found to possess some interest, not only as a record of actual experience, but also as indicating, to some extent, the relative expense of piercing different strata:—

Name of Tunnel.	Name of Railway.	Length.	Strata.	Cost per Lineal Yard.
		Lin. Yds.		£.
Guildford . .	London and South-Western.	965	Chalk . .	30
St. Catherine's .	Ditto	191	Sand . . .	40
Petersfield . .	Portsmouth	484	Chalk . .	30
Salisbury . .	London and South-Western.	440	Chalk . .	30
Honiton . . .	Ditto	1,350	Red marl and green sand	50
Lydgate . . .	London and North-Western.	1,332	Coal measures	30
Buckhorn Weston	Salisbury and Yeovil. . .	739	Clay . . .	72

Mr. C. B. **Lane** gave a description of a tunnel executed by him in the years 1843 and 1844, as resident assistant to the late Mr. Brunel, on the Bristol and Gloucester Railway, Fig. 1, p. 382. The tunnel was situated at Stapleton, about 3 miles from Bristol, and was carried through the shales of the coal measures, locally called 'duns.' The ground, from the fact of an old tunnel (shown by dotted lines on the cross section) having been carried through the same place, and also from some old coal workings, was in a very shaky condition. The tunnel was constructed for a double broad-gauge line, its east side being occupied by the old tunnel, which was about 9 feet wide and 12 feet high, through which the traffic on the Coal Pit Heath Railway, leading from Bristol to Westerleigh, was originally carried. The work was commenced in 1843 during a dry summer, and there being no appearance at first of the pressure that afterwards exhibited itself, the arch work was carried on with only four rings of brickwork in mortar. When the autumnal rains set in, the ground began to press heavily, so much so that the whole line of the tunnel could be traced along the surface; and it pressed all the more heavily from the fact, that the greatest depth over the arch was not more than 40 feet. On the 10th November, 1843, a length of the tunnel fell in, and it was found necessary to proceed with the centering as rapidly as possible, to prevent the whole of the work, so far as then constructed, from falling; and before completion, upwards of 200 lineal yards of the arch had to be taken out and rebuilt. After this accident the dimensions of the brickwork were considerably increased, and Roman cement was employed. The late Mr. Robert Stephenson the highest authority the profession had had on practical questions, —had said, that more was to be learned from failures, than from successes, and it was on that account that Mr. Lane ventured to bring forward the facts relating to this tunnel, as a warning to Engineers not to incur unnecessary risks in tunnels. During the progress of the work, some little embarrassment was caused by the necessity of keeping the small tunnel open for traffic; but no interruption occurred until the accident of which he had spoken, and that casualty was happily unattended with loss of human life. He had at first used such centres as were employed in the Buckhorn Weston Tunnel (Plate 8, Fig. 6); but he thought it scarcely possible to devise a more inconvenient centre for a tunnel: subsequently skeleton ribs were used of the kind shown in Fig. 1. There were great objections to the use of timber centres in a tunnel, and he preferred wrought-iron centres, like those used in the construction of the Metropolitan Railway, which must be pronounced most valuable contrivances. The total length of the Stapleton Tunnel was 514 yards. It was 26 feet wide at the level of the rails, 28 feet at the springing, and 24 feet high. The side walls were built of sound-fitted rubble work, of Pennant sandstone; and the arch of brickwork was laid in lias lime mortar up to the time of the accident, after which Roman cement was chiefly employed. At the conclusion of the work the arch stood thus:—

Fig. 1.



Stapleton Tunnel, Bristol and Gloucester Railway.

Brickwork in Cement:—	
6 rings thick	122 lin. yards.
5 " "	280 " "
Brickwork in Mortar:—	
6 rings thick	10 " "
5 " "	48 " "
4 " "	47 " "
Coursed rubble in mortar, 2 feet thick	7 " "
	514 yards.

The work was executed in one hundred and thirty lengths, the greatest being 16 feet, the least 6 feet, and the average about 12 feet. Where there was much lateral pressure an invert was put in.

The total quantity of oak bars and props broken, or otherwise destroyed, in timbering the excavations was 6,715 feet, or 13 feet per lineal yard of tunnel. The quantity of poling boards unavoidably left in amounted to about 50 superficial feet per lineal yard of tunnel. The greatest number of bars used in one length was thirty-four, and the greatest number broken in one length twenty-three. From eight lengths only was all the timber saved. The average for the labour for brickwork in cement (the three rings next the soffit being laid header and stretcher) was 1 bricklayer and 1½ labourer to 1·8 cubic yard of brickwork; for the masonry, 1 mason and 1 labourer gave 2⅔ cubic yards on the average per day. The price allowed for centre setting, including the profiles, was 10 shillings per rib. Bristol bricks were delivered for 29 shillings per thousand, and Keynsham lime for about fourpence a bushel. The Roman cement was gauged with ashes in the proportion of 2 to 1, and gave an average, including all waste, of about 2 cwt. 3 qrs. per cubic yard of brickwork. The oak bars cost eightpence per lineal foot, and elm poling boards 16 shillings per 100 square feet. The contract price for ordinary excavation in the tunnel was 3*s.* 6*d.* per cubic yard, and for rock 7*s.* The brickwork in mortar was 25 shillings, and in cement 30 shillings, the rubble masonry in mortar 15 shillings per cubic yard, and ashlar 2 shillings per cubic foot. Mr. John Pritchard was the contractor.

Mr. HAWKSHAW, President, trusted that because the Paper did not elicit much discussion, it would not be considered the less valuable. The fact was, a plain and accurate description of important works was perhaps the most useful kind of communication that could be laid before the Institution. The discussions were doubtless very interesting, but the most valuable permanent records for the

'Minutes of Proceedings' were drawings and descriptions of works of magnitude, and the detailed experience of those who had superintended them. He therefore felt personally obliged to Mr. Fraser—and he was sure the Institution joined in that feeling—for the Paper he had laid before them. It related to a class of work which often presented great difficulties; and he was quite sure if carefully-prepared accounts were brought forward, of all those modes and processes which Engineers had recourse to in constructing the tunnels in this country, it would afford, especially to the younger members of the profession, most important and valuable information.

No. 1,089.—"Public Works in Pernambuco, in the Empire of Brazil." By William Michael Peniston, M. Inst. C.E.

The object of this Paper is to describe a few of the Public Works of one of the most extensive, productive, and yet the least known empires of the world. There are difficulties, however, to be met with at the outset, in the want of statistical information, the absence of correct maps, and the uncertainty as to what are called standards of measure in Brazil. Pernambuco is one of the principal, but by no means the largest, of the twenty provinces of which the empire consists. It has an area about equal to England, whilst its population is estimated not to exceed one million. It is so directly in the course of sailing-vessels bound to Australia, the Cape of Good Hope, and Cape Horn, that most of them sight the coast of Pernambuco on their way out. The Royal Mail steamers for Brazil and the Rio Plata leave monthly from Southampton, and make two stoppages for coal, at Lisbon and at St. Vincent's, on the voyage out. At the latter place there is a detention of two, three, or even four days, arising from the great demand at this mid-ocean depôt, and the want of adequate arrangements. The distance from England is a little above 4,000 miles. The mail steamers make the passage out in nineteen days; and on each of the three trips the Author has taken, leaving Southampton on the afternoon of the 9th, the arrival at Pernambuco has never varied an hour from 8 A.M. on the 28th of the same month.

The appearance of the town of Pernambuco from the sea is not imposing; being built on a low, sandy, flat, only a few feet above the level of the ocean. This flat is surrounded, at a distance of from 3 miles to 5 miles, by an amphitheatre of hills, the rising ground on the north side being extremely beautiful, and on it was built the original capital of the Province Olinda, so named from the exclamation of admiration uttered by the first discoverers of South America, "O! linda bellissima!" most beautiful place. The commercial capital was soon after removed to its present position, on account of the natural harbour formed there by a Reef, or in Portuguese, Recife, which is the true name of the capital, although Europeans generally speak of the town as Pernambuco, which properly only applies to the province. This reef runs for hundreds of leagues parallel to, and at only a short distance from, the coast. A little further south it is reported to be of coral; but in the immediate neighbourhood of Recife it is composed of soft, calcareous, and silicious sandstone, the sand of which is similar to that found on the adjoining beach, intermixed with shells of existing species. The reef is here about 100 feet wide and 3 feet above high water; it is stratified, and dips to the east, on which side it has a long, flat slope; but on the side next the harbour it is nearly vertical. The width of the channel increases considerably, between the town and the opening in the reef which forms the entrance to the harbour from the Atlantic Ocean; and at the widest part, just inside the entrance, a shoal, or bar, is formed, which has, until very lately, prevented any vessel entering which drew more than 16 feet of water. The Government are now, however, extending the quay walls of the Marine Arsenal towards the entrance of the harbour, thus equalising the channel area; and by the use of a dredger on the shoal, (which is of no great width), there has been already excavated a channel which admits vessels of 18 feet draft. This channel does not present, as yet, any indication of a tendency to refill.

In consequence of the absence of quays with sufficient depth of water for vessels to come alongside, all cargoes have to be shipped and discharged by means of lighters, the owners of which enjoy a practical monopoly. The usual charge for lighterage is one milreis per ton, to be paid by the ship, and one more by the receiver of the goods, or 4*s.* 6*d.* per ton in all. Occasionally this charge has amounted to ten milreis, or 22*s.* 6*d.* per ton, although the distance to the shore does not exceed half a mile.

The number of foreign vessels entering the harbour annually is about three hundred and fifty, averaging 250 tons each. The coasting trade is carried on principally by the Pernambucana Steam Boat Company, which enjoys a grant from the Government, covering all the working expenses, but has not yet been able to pay a dividend. There is a fair trade carried on by Barcassas, or sailing barges, of from 15 tons to 25 tons, which run up the mouths of the smaller rivers, to receive and discharge their cargoes. The 'Jangada,' or Raft, (of which a model is exhibited,) although not available for the carriage of cargo, is used to a great extent for fishing, and as a passage-boat, for hundreds of miles along the coast. The same craft, without its sails and shelter, is used at all ferries in the rivers of the interior.

There is properly no river navigation in Pernambuco; but the São Francisco, which rises among the hills, in the rich mining district at the back of Rio de Janeiro, flows northward from Minas Geraes till it enters the Province at its south-west angle. It there precipitates itself over the Falls of Paulo Affonso, a depth of nearly 200 feet, whence it takes its course through a rocky rapid channel for nearly 200 miles to the sea. Above the Falls of Paulo Affonso, the São Francisco is navigable to the Falls of Pira Póra, a distance of from 600 miles to 800 miles, and it is to this, as a feeder, that the railways from Recife and Bahia are both directed.

Nothing can exceed the richness of the soil in the valleys in the interior, which are principally devoted to the growth of sugar. This in general is very poorly cultivated, and the manufacture is worse conducted, only from 50 to 75 per cent. of the saccharine being extracted from the cane. The produce is sent on horses' backs from 70 to 100 miles to the port. In the height of the sugar season, eight thousand horses so laden usually arrive daily; the quantity annually exported from Recife varying from 60,000 to 70,000 tons. Cotton is occasionally found growing wild; and is cultivated only in the far interior. It is also sent to the port on horses' backs from distances varying from 200 to 500 miles; the annual export being from 20,000 to 25,000 bags of 170 lbs. each. Hides, rum, dye and fancy woods, with cotton and sugar, form the principal exports; but tobacco, coffee, rice, Indian corn, mandioca, and beans are cultivated largely for home consumption.

The principal imports are manufactured cotton goods, hardware, dried fish from Newfoundland, and dried beef from Buenos Ayres and from Rio Grande do Sul. The duty chargeable on imported goods varies from 2 to 60 per cent., averaging say 30 per cent.; while the duties on exports are only about 8 per cent. All articles required for the construction, or the working of a railway are allowed to pass free. But the number of forms to be gone through involves delays and annoyances, which will be much lessened by adopting the courtesies of the country.

The base of the currency of Brazil is the real, one thousand of which are a milreis, equal to 2*s.* 3*d.* English. Large amounts are reckoned by contos, or one thousand milreis, equal to £112. 10*s.* The milreis has been stated to be equal to 2*s.* 3*d.* English; but it is subject to constant fluctuations, according to the rate of exchange, 27*d.* being taken as par. In 1858 and 1859 it was so much below par, that the salaries of Englishmen, estimated by the milreis at par, required an addition of 8 per cent. Whilst on some occasions in times past business has been done at 24*d.*, advices by the last mail show that it had risen to 30*d.*, an exceptional case, it is presumed, for a paper currency. Wages are usually reckoned by parts of the milreis, called by the native workmen patacas, the milreis being equal to 3 patacas. Thus men are spoken of, as well as wages, as being from 3, 3½, 4, 4½ or 5 patacas—the usual limits of range, or from 2*s.* 3*d.* to 3*s.* 7*d.* The Government rate of interest is 7 per cent. The banks give 8, but 10 and 12 per cent. are easily procurable on very good security; and 1½ per cent. per month is by no means an unusual interest for the senhors to pay for money advanced on the security of the crops.

The ordinary measure of weight is the aroba, equal to 32 lbs.

English, or 70 to the ton. The cubical measure for dry goods is the alqueire. This varies considerably at different places, nearly every town having its own standard. At Recife, the capital of the province, the standard alqueire measures 2·93 cubic feet; whilst at Villa do Cabo, within 20 miles, the standard measures only 2·18 cubic feet. The national standard of length, the braça, or fathom, was defined, in 1852, to be the $\frac{1}{3000}$th part of a league of eighteen leagues to the degree, without specifying where the degree was to be taken. By the law of 1857, it is fixed that the braça is to be equal to 22 decimetres, or 7·218 feet; and the league is sometimes estimated at 3,000 braças and sometimes at 2,400 braças. The palmo, or hand, is one-tenth of the braça. Besides these two national measures, the French metre is frequently used. Most small dimensions are given in polegados, or inches, and here a further difficulty arises, owing to the difference between the Portuguese and the English inch, both of which are used, the Portuguese being to the English as 1·000 to 1·082.

If it were not for the occasional outbreaks of yellow fever, the climate of Pernambuco would be most enjoyable; but so sudden and sweeping are the attacks of that malady, that panics are frequently created, and the dread of it operates, long after it has disappeared, to prevent the full enjoyment of the climate. It is, however, rare that fatal cases occur with men of good constitution, of cleanly and regular habits, and who take frequent and active exercise. People of sedentary habits, sailors, navvies, mechanics, and all who give way to a dirty, loose mode of living, are its usual victims; but it is a curious fact, that at a time when nearly every vessel in the harbour of Recife was losing numbers of its sailors by fever, vessels alongside with creosoted sleepers on board never lost one. Occasional outbreaks of cholera have been very fatal amongst the slave population, whilst small-pox has made great ravages with the natives; but these complaints are confined almost exclusively to those classes. The healthiness of Pernambuco may be gathered from this, that although all seek to avoid the city of Recife as less healthy than the country, yet in the city with a population of 120,000 persons, until lately without a single closet, or any drainage whatever, and with a daily consumption of water of only $\frac{3}{4}$ gallon per person, the rate of mortality is only $1\frac{3}{4}$ per cent. per annum.

The variations in temperature are considerably less, and the regularity at any hour much greater, than in this country. For the five, or six summer months, the temperature does not vary more than 4° above, or below 82° at 9 A.M. in the shade, nor 4° above, or below 78° at the same time for the winter months. The mean maximum temperature in the shade for the year 1861 was 84·4°, and the mean minimum in the shade for the same year 68·8°. December was the hottest month, viz. 90° in the shade.

July was the coldest month 85·75° in the shade. During the night, the average lowest temperature was 64·5° in September, and the average highest was 71·75° in April. The highest temperature in the shade was 92° in June, and in the sun it was 148° in November.

The total fall of rain in . .	1860	was	67·20 inches.
„ „	1861	„	123·75 „
For the first six months in . .	1862	„	53·64 „
The wettest month in . . .	1860	„	June.
„ „	1861	„	January.
„ „	1862	„	March.

The extreme recorded rain-fall was 7·25 inches in twenty-four hours, of which upwards of 4 inches fell in six hours; this was in January 1861. The highest floods in the valleys crossed by the Recife and São Francisco Railway vary from 15 feet to 25 feet; but they rise very rapidly, as frequently the river is in its usual quiescent state in the evening, and in the morning is a raging torrent.

The coast of Pernambuco is peculiarly free from storms, the winds being as regular as they are proverbially uncertain in this country. The prevailing winds are from the east, veering a little to the south when the sun is in the northern hemisphere, and a little to the north of east when the sun is in the southern hemisphere. Towards evening a land-wind springs up, which falls again in the morning; and for the hour, or two after the land-breeze has fallen, and before the sea-breeze sets in, the heat is more sensible than at any other hour of the day. The regularity of the wind on the coast of Pernambuco has directed the Author's attention to it as a motive power, there being no water-power to compete with it, and the cost of fuel being a serious objection to the use of the steam-engine.

The geological character of the province is chiefly of the Plutonic type, the base being almost invariably granitic, or metamorphic. The most prominent hills are of granite at their summits; but the smaller hills are generally of decomposed schist or gneiss, the decomposed material still retaining the appearance of the rock, though perfectly soft. In some instances the section represents an intermixture of boulders and coarse water-worn gravel, entirely decomposed and quite soft, working like the oolitic sands. There are several indications of trap rock, from St. Antão in the south-west to Ilha, near Recife; and the island of São Aleixo, near Serenhaem, on the eastern coast, is of the same class of rock.

The waterworks for the supply of Recife consist of a natural reservoir among the hills, about 33 feet above and 9 miles from

Recife, to which the water is conveyed by a main 12 inches diameter, and is distributed by thirteen stand-pipes and fountains in different parts of the town, and sold at the rate of about a halfpenny per cubic foot. The ships in the harbour and the villages in the suburbs are supplied by lighters and canoes at the same rate. The works have been very ably executed, under the direction of Mr. Bowman, an English Engineer long resident in Recife. They cost less than the estimate, and yield about 15 per cent. per annum to the proprietors.

The gas-works of Pernambuco are of so late a date, that they have not yet been completed, as regards the accommodation to be rendered to the suburbs and the adjoining villages. They have been very well carried out by Messrs. Bellhouse, of Manchester, under the direction of Messrs. Law and Blount, Civil Engineers. There are now 1,100 public lights, and 2,800 private lights, supplied by about 30 miles of main and service pipes, from two gas-holders, 100 feet diameter and 18 feet deep, with a gas-making apparatus, consisting of sixty retorts, hydraulic mains, two vertical condensers, two dry-lime purifiers, a scrubber, exhausters, steam-engine and boiler, station-meter, governor, &c.

Up to a recent date there was no drainage, or sewerage, whatever in the town of Recife. The Government has now granted a concession to M. Cambronne, who undertakes to put a water-closet into every house, so constructed that all liquid matter is to pass into a system of pipe-drains, and all solid matter into a closed barrel, which is to be removed once a week to an establishment outside the town, where the contents are to be converted into a dry manure. A regular rate has been fixed at which the closets are to be supplied, and a fixed annual sum is to be paid by each householder, for the service of emptying the barrels.

The streets of the city proper, where the traffic is heavy, are pitched, or very roughly paved, with stones of any size, or shape, consisting mainly of granite taken out of vessels in ballast from Europe. The streets being extremely narrow, the traffic is usually worked over them by long, low trucks, from 6 feet to 8 feet in length, about 2 feet in height, and 2 feet 6 inches wide, hauled by a single bullock. These trucks suit the goods which form the principal traffic very well, as this consists of sugar in bags of about 1½ cwt. The side streets and the thoroughfares in the suburbs are sand tracks in summer, and frequently watercourses in winter; but this is being altered, under the direction of Mr. W. Martineau (M. Inst. C.E.), the Government Engineer. Outside the town there are four principal roads, about 20 to 25 miles in length each from the capital, leading south towards Rio Formoso, south-west to Victoria, or São Antão, west to Paó D'Alho, and north to Iguarassu. The total length of road passable during the greater part of the year for wheeled carriages throughout the province is about 130 miles. Of this about one-sixth only is metalled. It is considered that, in clay districts, metalling alone is available to make a passable road; but in districts where the soil is favourable and the drainage is good, a fair road may be made by a proper admixture of clay and sand, provided it has a sufficient rise in the centre. This mixture soon gets beaten hard, and endures a good deal of bad weather before it gives way.

In some districts the roads made by the Government are practically useless, from the want of bridges across the rivers; in others timber bridges have been built. These usually have brick abutments, and piers of timber piles 'wriggled' in, the use of the pile-engine being almost unknown. On the piles so driven, cap-sills are fixed, and two, three, or four longitudinals, according to the width, which is ordinarily 15 feet, are laid throughout from abutment to abutment. On these, cross timbers from 6 inches to 8 inches square are laid side by side, and these form the road on which the wheels run. The want of sufficient bearing in the piles, and the rapid decay of timber in that climate, makes these bridges a constant source of trouble and expense. Therefore for the bridges on the new roads now being made iron has been adopted. The São João bridge, on the Paó d'Alho road, consisting of four spans of 60 feet each, is a fair example of the class of structure now being introduced by the Government Engineer. Besides these public road bridges, there is a new iron bridge in the town of Recife, erected from the designs of Mr. Edwin Clark (M. Inst. C.E.), of which Messrs. Horace Green and Co. were the contractors.

In districts adjoining the capital, and in bad clay, or for heavy traffic, the road is metalled with broken granite, mostly brought from Europe as ships' ballast, to a width of from 12 feet to 15 feet and about 9 inches in thickness, wide spaces being formed on each side for horse traffic, as the horses are never shod.

The cost of these roads has been, in times past, almost fabulous, exceeding that of European railways. But according to the latest contracts, the cost has been under £3,000 a mile, including the bridges, but exclusive of the metalling, which latter a short time back amounted to upwards of one pound sterling per cubic yard, when broken and spread in place. It may be noted that these roads were generally made from a sketch map, the distances being plotted approximately by the time occupied in walking from one place to another. The preparation of the survey followed the completion of the work.

Next in order to the public roads come the bullock tracks, made and repaired by some proprietors through their own estates, where carts can travel during the summer months; but these are little used, and indeed are scarcely available, for public traffic.

The main traffic of the country is at present carried on by pack horses, on tracks barely wide enough for two horses to pass each other, and pursuing a course so devious as to lead one to speculate what could have been their origin; certainly not to take the most level course, for they frequently mount the highest hills, apparently only for the purpose of descending them again. In winter, the constant working of the horses' feet, each following in the leader's track, works these roads into a series of ridges and furrows, which run with the greatest regularity across the track; and it is not at all unusual for the horsemen's feet, or the horses' girths, to be touching the tops of the ridges between the furrows, or trenches, in which the horses walk. The pack horses as a rule are not larger than English ponies, or cob horses, carrying from 250 lbs. to 300 lbs., a distance of from 20 to 25 miles per day, at a charge of from 6*s.* 6*d.* to 11*s.* 3*d.* Neither the horses nor the drivers are at present available for any draught work; and for railway purposes it has been found necessary to introduce English horses and English drivers. The system of feeding is not conducive to hard work, being ordinarily grass of the country, called 'capim,' with molasses and water.[1]

On the estates adjoining the Government roads, and for the work of the Engenhos themselves, bullock carts are used for transport. These consist of a pair of cheese wheels, 4 feet diameter, keyed on to a wooden axle. The bed of the cart is framed on to the wooden pole, and seated on the axle, by means of two wooden bearings, or plumber blocks. To the pole are generally attached three pair of oxen, whose daily duty is about 10 miles, the average load not exceeding 15 cwt. The charge per day for a pair of bullocks varies from 9*s.* to 13*s.* 6*d.*

To render this state of affairs more apparent, imagine, if possible, the following parallel case. Suppose England to be part of an empire extending from the Straits of Gibraltar to the North Cape in the Arctic Ocean, which is exactly the extent of the seaboard of the Brazilian empire. That London, as the capital, had one road, partly formed, but not metalled, to Staines; a second road partially metalled to Reading; a third formed, but with bridges incomplete, to Watford; and a fourth just completed to Barnet. That none of these roads could take more than lightly-laden carts, and that all beyond and between was wild country, with horse tracks alone; such was the condition of Pernambuco before the railway was commenced. But in justice to Brazil it is necessary to carry the case a little further, and suppose, as is the fact, that this vast empire only obtained its constitution in 1825, and was only firmly established as an empire in 1831, on the accession of the present Emperor, and the surprise will be not that there are no detailed records, or statistical accounts, of public works, but that there are any public works at all to compare with those existing in the old-established countries of Europe.[1]

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[1] This only applies to the district within a hundred miles from the sea-coast; in the interior horses regularly working are fed chiefly on 'milho' (Indian corn) during the dry season.—W. M. P.

The absence of river navigation, the inefficiency and great cost of public roads, and the horrible character of the common roads of the country, led very naturally to the consideration of a railway, which was brought forward by the Messrs. de Mornay, English Engineers engaged in Brazil, who, whilst executing some improvements in sugar machinery, became acquainted with the urgent wants of the district. Their project was to carry a line through the entire length of the province, from Recife, the capital, to the Falls of Paulo Affonso, on the Rio São Francisco. This being well recommended to the Government, received its sanction, and a concession was granted for the whole line, with a guarantee of 5 per cent. from the Imperial Government and 2 per cent. from the Provincial Government, upon the estimated cost of completing the first portion of the line, from Recife to the River Una, a distance of about 75 miles. Besides the guaranteed interest, it was conceded, that there should be no other line within 20 miles; that Government land should be supplied free of cost, and the right of working, or letting the minerals for 20 miles on each side; that there should be powers of deviation for a mile on each side; that native labourers on the works should be exempt from impressment in the National Guard; and that all materials required from Europe should be admitted free of duty.

The original estimate was for a line on the North American system at £540,100. By the advice of the late Mr. R. Stephenson, M.P. (Past President Inst. C.E.), the late Mr. Borthwick (M. Inst. C.E.), went out to examine the line. He recommended considerable alterations and revised the estimate, which was increased to £875,123. Further improvements were afterwards introduced, and the capital was increased to £1,200,000, to which amount the guarantee on the part of the Government was extended; but even this has not sufficed to complete the line, and the Brazilian Government have now agreed to a further extension of the capital, to cover the amount actually expended on the works.

The inspection and control of the Government have been confined to examining and reporting on the character and mode of execution of the works. This duty has been performed by Engineers-

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[1] At Rio de Janeiro there are some very good roads, one of which is equal to the best macadamized roads in England, and is upwards of 100 miles in length, extending from the terminus of the Mauá Railway, near Rio de Janeiro, to Juiz de Fora in the Province of Minas Geraes.—W. M. P.

Fiscal, generally Brazilians resident in Recife, assisted occasionally by the Engineer to the Province, Mr. Martineau, and subject to periodical inspection by the Consulting Engineer to the Imperial Government, Mr. C. B. Lane (M. Inst. C.E.). It would be unreasonable to expect, that public works, like railways, could be carried on without giving rise to differences of opinion between Engineers representing interests sometimes at variance; yet it is a bare act of justice to state, that the Government Engineers have performed their duty with a fairness worthy of the liberal Government they represent.

The character of the country traversed by the first portion of the Recife and São Francisco Railway, from Recife to the River Una, presents a great uniformity in its physical features. It consists of a succession of narrow valleys, with hills from 100 feet to 150 feet in height, the sides being very thickly wooded, composed almost without exception of rock of a granitic character, varying from a state of perfect decomposition to its natural hardness, the proportion of soft ground to hard rock being at least 10 to 1. It was decided, by the Concession, that the curves should not be sharper than 20 chains radius, or the gradients steeper than 1 in 80, nor longer, at that inclination, than 2 miles. The character of the country may be gathered from this, that in no case has the specified gradient approached the limited length, and in two cases only has it exceeded 1 mile in length.

One tunnel only has been required, and that under 500 feet in length. A short tunnel like this for a single line, through easy ground, and with very inexpensive, unornamental fronts, would require no particular description, were it not that its position rendered it desirable to effect a communication through it, for the conveyance of materials to the upper portion of the works. When, therefore, the small trial heading had shown that the ground was favourable, as the materials for the permanent tunnel were not at hand, and there was plenty of timber on the ground adjoining, it was decided to enlarge the heading sufficiently to take an engine through, minus the chimney. This was effected without difficulty, and a constant stream of materials passed through, during meal times, without interfering with the work. With the like objects, of keeping up the supply of materials and of not delaying the tunnel, the mode of execution was varied to the following extent; as soon as the end lengths had been completed in the usual manner, a surplus stock of materials was sent through so as to last for a few days; the road was then broken up, the invert was built throughout, and the road was re-laid; after which the tunnel and the supply of materials went on without interfering one with another. The size of the large heading was 9 feet 6 inches wide at the bottom, 8 feet wide at the top, and 10 feet high. The invert and arch of the tunnel were of brickwork, with side walls of rubble masonry, and the cost was 13*s.* 6*d.* per yard for labour only.

The earthworks of the heaviest 20 miles have amounted to about 800,000 cubic yards, or 40,000 cubic yards per mile; which is about double the other parts of the line. The highest embankment and the deepest cutting have been about 40 feet. The dimensions usually adopted are, for cuttings a width at the formation level of 20 feet, which includes a 2-feet drain on each side, the slopes varying according to the ground. In rock cuttings the width is reduced to 10 feet, with a drain down the centre. The width of the embankments at the formation level is 16 feet, with slopes of about 1½ to 1. The formation surface is trimmed 6 inches lower on the outside than in the centre, and is kept 18 inches above the level of the highest known floods. This gives, usually, a preponderance to the quantities in the embankments, as most of the valleys are subject to floods. The balance of quantities has been further disturbed by its having frequently been found preferable to make up the shallow banks in part from side cutting, rather than from a long 'lead,' and then to complete them to the full dimensions, after the rails were laid. It is necessary to bear this in mind, or the section, however carefully taken, will not represent the quantities actually to be executed.

There are eight principal bridges, all of iron, in the length of about 75 miles. They vary in height from 15 feet to 25 feet, and are of the following spans:—No. 1 has five 60 feet spans, No. 2 six 60 feet spans, No. 3 three 60 feet spans, No. 4 two 60 feet spans, No. 5 one 80 feet span and one 50 feet span, No. 6 one 80 feet span, No. 7 two 60 feet spans, and No. 8 two 90 feet spans.

The smaller streams are carried under the railway by open culverts where practicable, small iron girders being used to carry the railway across them, when their spans exceed 4 feet. Where this mode has not been possible, the usual form of brick culvert has been adopted.

The fencing found to answer best is a ditch and bank, the latter being planted at the proper season with the native thorn. This fencing serves its purpose very well; but the real difficulty is to keep people from trespassing along the line, which not only the people of the country, but those in subordinate authority, think they have a perfect right to do.

The permanent way, for the first and second divisions, consists of a double-headed rail, weighing 80 lbs. per yard, with creosoted larch cross-sleepers laid at intervals of 3 feet, on the average. The rail is fixed in cast-iron chairs, weighing 24½ lbs. each, the joint chair being 39 lbs. weight. Each chair is fixed to the sleeper by two spikes ⅞ths of an inch diameter. The rails were at first laid without fish plates, but these have since been added, and the weight of the rails, on the remaining portion of the line, has been reduced to 72 lbs. to the yard. About 10 miles of the permanent way have been laid, as an experiment, with Greaves' 'pot' sleepers. They have answered very well generally, but in a wet bottom, or on high embankments, the line, so constructed, does not remain in such a good condition as when cross-sleepers are used. An experiment is being tried with sleepers of native timber, of which there are in the woods adjoining the line nearly a dozen different kinds, that are understood to be sufficiently durable for the purpose. These are Sapucaia de Peilão, Paó d'Arco, Aroeira, Coracão de Negro, Maria Preta, Sedro, Amarella, Paó Ferro, Emberiba, Murici, and Visgeira. The price at which these can be delivered is one-third that of creosoted sleepers. The only question is whether such caution can be exercised in the selection of the timber as shall insure its being of the right sort. They possess this advantage, that when the chair is once well spiked to them it becomes a matter of great difficulty, in fact almost an impossibility, to draw the spikes. There have been instances of failure in the creosoted sleepers sent out from England, but they have stood much better than the compressed keys, which have had to be entirely replaced. There are several kinds of native timber available for this purpose. Those now being used are made of wood called 'Oiticica,' or of 'Sicupira.' They are steeped in creosote for about three months, there being at present no means of putting them under pressure. The ballast for the whole of the first division, or 20 miles of the line, is composed exclusively of sand. For about 9 miles of this distance the line passes through a series of small sand hills. On the second division the ballast is composed partly of decomposed granite, 'topped' with the sand from the first division; but the upper part of this division, and the whole of the third and fourth divisions, are ballasted with a coarse sand found on the adjoining river banks.

The stations and line arrangements are of the simplest description. The station at Recife is at present a temporary one, on the understanding that the line, which now terminates at the suburb of Cinco Pontas, will be advanced to a more central situation in the city. The intermediate stations each consist of a booking-office 12 feet square, and a passengers' waiting-room of the same size, with a porch between them. These stations, twelve in number, are provided with sidings only; but there are three larger stations where goods sheds are provided, and two have running sheds for the engines. There is not the slightest attempt at ornament in any of the buildings, which have been executed in the simplest way, with the best materials, and with a view to the extension of the accommodation as the traffic increases.

The locomotive engines, carriages, and part of the goods waggons were manufactured in England; the engines by Messrs. Robert Stephenson and Co., the passenger carriages by Messrs. Wright & Co., and the goods waggons by Messrs. Brown, Marshall, and Co.

The engines have done, and are doing, their work in that first-rate style for which Messrs. Robert Stephenson and Co. are celebrated. The passenger carriages are from the designs of Mr. Edward de Mornay, the original Concessionaire of the line, whose ideas have been ably carried out by Messrs. Wright & Co. They have succeeded in building a carriage reputed to be one of the best for tropical climates. It has one peculiarity, however; the projection of the double roof gives a total width of 12 feet, and necessitates a middle track, or space between the rails, of 7 feet 6 inches, instead of the ordinary width of 6 feet. The goods waggons generally have been made in Brazil, and for this purpose, as well as for the ordinary uses of the line, the Company established workshops at Barbalho, near the upper end of the first division.

It was originally proposed that the engine-shed and repairing shops should be built on waterside property, adjoining the harbour of Recife; but about the time they were to have been commenced, there occurred an outbreak of yellow fever, which carried off several of the English foremen and mechanics, and frightened away so many others, that it was decided to establish the locomotive depôt at Barbalho, about twenty miles up the line, as this had the reputation of being a much healthier place. The general arrangement of the workshops and men's quarters is that of a hollow square, but only such portions were executed as were required from time to time. On one side, abutting on the line, are the shops and running shed;—on the second side are the married men's cottages;—at the back are the single men's quarters;—and on the further side, on a mound overlooking the whole, is the locomotive superintendent's house and offices. The workshops cover a space of 180 feet by 160 feet, and consist of one central space of 30 feet with a traversing frame running through the centre of the shops, by which engines, or carriages, can be brought in from the line, and be placed in either of the side stalls, which are all 20 feet wide. The roof, of which the tie-beam is 15 feet from the rails, is supported internally by pillars of native timber, and externally by brick piers 3 feet by 2½ feet at the sides, and the end finished under each principal with arches. The spaces on each side of the traversing frame are again divided into four nearly equal areas. One of these serves as a general fitting and repairing shop for engines; and opposite this, on the other side of the traverse, are the forges, lathes, iron planing machine, &c., whilst the space devoted to waggon building and carriage repairs is situated opposite to the saw benches, wood planing and morticing machines. In a detached building adjoining the running shed, is a small foundry, capable of producing all the ordinary small castings of iron, or brass, usually required for rolling stock and repairs. The following is the list of a tools fixed in the different shops:—25 H.P. engine and boiler; wheel turning lathe; lathe with 17-inch centres; ditto with 8-inch centres; screw cutting lathe with 10-inch centres; screwing, slotting, planing, and vertical drilling machines; 6 fan blasts for smiths' hearths, and 2 ditto for the foundry; 6 smiths' hearths; crane; 2 double-throw pumps; with the necessary shafting, pulleys, drums, &c. In the wood machinery shop are the following: planing, tenoning, morticing, rebating and drilling machines; 3 circular saw benches, and a self-acting saw bench; vertical saw sweep; turning lathe; grindstone, circular oil stone, with shafting, drums, pulleys, &c. This establishment has at present proved amply sufficient for the purposes of the line.

The first concession from the Brazilian Government was dated June 1852; the last in December 1855. The actual work was commenced in May 1856. The first division of about 20 miles was opened in February 1858; the second on the 16th December 1860; the third and part of the fourth on the 26th May 1862; and the whole of the first section to the River Una was finally opened in November 1862.

The best evidence that the working arrangements have been well carried out is, that during the five years the line has been in operation there has not been an accident to a passenger. The want of any railway experience on the part of the officials connected with the traffic, who, excepting the traffic-manager, are all natives, threw a much greater amount of duty and responsibility on the locomotive superintendent and the engine-drivers than is usual in this country. The line was opened as a single way without a station-master, or a native official who could give a correct signal, so that the engine-drivers were obliged to judge for themselves; each acted every journey under written instructions from the locomotive superintendent, in whom was vested the sole authority to regulate the motions of the trains. The same plan was adopted on parts of the line under construction, and has been attended with perfect success, even when five engines have been at work at the same time on a length of 20 miles of single line.

The maintenance of the permanent way has been carried on by native labourers,—a gang of six of whom, under a Brazilian, or a Portuguese ganger, takes charge of three-quarters of a league, or nearly three English miles; the whole being under the inspection of English foremen, each of whom takes a district of about 20 miles.

The labour question is one of the most vital importance to the future of Brazil; for upon it will depend not alone the conditions on which Public Works can be executed, but however favourably they may be carried out, their ultimate success is contingent on the extension of trade and agriculture, which again are absolutely dependent on the supply of the requisite amount of labour Agricultural operations have heretofore been conducted exclusively by slaves, as has also, mainly, the work of porters and lightermen about the ships, and the harbour and warehouses of Recife, where the absence of all mechanical appliances renders these operations of more relative importance than in England. The laws, however, against the further importation of slaves having been strictly enforced for some years past, the number has gradually decreased, and as the concessions for the prosecution of public works now prohibit the employment of slaves, that class of labour may be excluded from further consideration in this Paper. Liberal concessions have been granted, from time to time, by the Brazilian Government, for the promotion of colonisation, but with no commensurate success;—one or two unimportant German colonies being the only result. Attempts have been made to introduce coolies, and lately to import a large body of Germans for one of the public works of Pernambuco, which has resulted in a most signal failure. No positive conclusions can be drawn from these endeavours, as it is well understood that in the former instance failure arose from the business being transacted in too speculative a spirit, and in the latter from the want of the exercise of proper judgment in the selection of the men. Portuguese, and men from the western isles supposed to have been colonists from Portugal, succeed very well in Pernambuco. There are a few instances of Frenchmen and Piedmontese standing the climate better than Englishmen,—but all that can be reasonably obtained would not more than suffice for foremen and leading men for the public works of the province, leaving the main labour to be performed by the natives.

Experience has proved that, both in the province of Pernambuco and in the adjoining provinces, there is an ample supply of manual labour for any public works, or extension of agricultural operations at present probable. Although men are to be found in the country, as they can easily maintain themselves, in their simple way of living, without work, they must first be persuaded, not only that it is to their advantage to work, but to leave their homes and families and to walk 200 or 300 miles to obtain employment. Then the native Brazilians are naturally a proud race; and as heretofore work has only been done by slaves, the free man considers it ‘infra dig.’ to be on terms of equality with them in this respect. Even when these difficulties have been overcome, the native Brazilians must be treated with such consideration, that it requires more tact, temper, and discretion, than are ordinarily to be found in an English ganger, or foreman, to keep them on the work. No consideration, whatever, pecuniary or otherwise, will prevent them from returning home, when the season arrives for looking after their little crops. This however generally happens about the rainy season, when their presence is less required on public works; and if treated kindly, and any hopes are held out of their being employed again, they will almost invariably return to the work. It is but right to say, that the consideration and courtesy the native workmen expect to receive from an Englishman, they pay to one another; and it is ridiculous to hear them in argument, and occasionally to find them in writing, addressing each other as 'Illustrissimo Senhor.' A gang of native labourers, on their first arrival from the interior, is always accompanied by a 'Cabo,' or keeper, who receives double their pay, and without whom they will not work. His duty is nominally to superintend the work, but in reality he sits listlessly by, smoking a cigar, and however irregular the workmen, the Cabo indignantly resents any interference, or remonstrance. For a long time all attempts to alter this system were vain; but the introduction of piece-work is gradually bringing about a better order of things. The only work that the native workmen is accustomed to is ditching, and the only tool is the hoe, with which he digs and scrapes the earth into a bank at the side. Specimens of this work may be found, in the boundary fences of the Engenhos in the interior, that for line and uniformity of slope could not be surpassed anywhere. This work costs on the average about 6*d.* or 7*d.* per cubic yard. The ditch varies from 6 to 10 feet wide, and 4 to 5 feet deep. The first lesson is to induce a native to give up the hoe, and take to the pick and shovel. Their want of order and discipline prevents them from working a barrow road properly, and they dread the operation of tipping a waggon; but a light hand-cart they work very well, and fill a set of ballast waggons in much less time than might be expected, but they will not continue their exertions. Four men will, in light dirt, excavate and fill a set of five-yard waggons in twenty-five, or thirty minutes, and on certain occasions they have been known to do it in twenty minutes. Their delight is then to run out with the waggons and engine to discharge the load, when they will jump about the waggons, and shout like madmen, or boys wild with excitement. It is scarcely possible to conceive a greater contrast than the present mode of working offers to the only one formerly adopted by the natives. An engine with twenty trucks carrying 100 cubic yards of dirt, or ballast, and eighty, or one hundred labourers will now run 2 or 3 miles and back again, in less time than they would, formerly, if left to themselves, have loaded about a barrow full of dirt on a distended ox-skin, and have drawn it by two oxen from 200 to 300 yards. Filling waggons, as above, costs 9*d.* to 10½*d.* per cubic yard, exclusive of road-laying and repairs. Men's wages vary from 3*s.* to 3*s.* 9*d.* per day, the latter pay being for picked men in all cases.

Although the difficulties are great in getting the native labourer into order, temper and perseverance will overcome these with time;

but with the native artisan the difficulties are greater still, as there are even in the principal towns, scarcely sufficient mechanics for the ordinary work, so that they are even more independent than the common labourer, and are infinitely more conceited and wedded to their own ways. It becomes, therefore, almost indispensable, that works of art should be executed by foreigners, with such assistance from the natives as can be obtained. The native country carpenter is not available, except with the assistance, and under the immediate inspection, of Europeans. He has but one tool, the incho, or hand adze, and with this he will, if left to himself, hew a piece of timber, 14 inches by 8 inches, to get a scantling of 6 inches by 4½ inches, rather than use the saw. When he does use the saw, he requires, even for common work, the aid of another man, who catching hold of the point of the saw with his fingers, helps the down cut. He can make a Brazilian roof, or rough door and shutter, (there are no windows in the interior); but he is entirely ignorant of staging, scaffolding, pile driving, or waggon building, and not having the slightest idea of square, or line, all his work must be set out. For such duty as the native carpenter can perform, he is paid from 4*s.* 6*d.* to 5*s.* 9*d.* per day. The bricklayer is also the mason, the plasterer, and the tiler, and of such men as are available for public works in the province, the same remark holds good as for the carpenters. They have not the remotest idea of bond, line, or level, and not only has the work to be set out, but sometimes two English workmen, one at each quoin, can scarcely keep the native workmen right between them. In consequence of the action of the atmosphere on the native bricks, it is usual to plaster all exposed work; and of this, as well as of the plastering of the interior of the houses, the native mason makes very tolerable work. He is also very handy in placing the native tiles, and at both these operations may be trusted by himself, with ordinary instruction and supervision. Brickwork and masonry cost, for labour only, from 9*s.* to 14*s.* per cubic yard, according to the thickness and the height. The wages vary from 4*s.* 3*d.* to 6*s.* 6*d.* per day. Native smiths have turned out better than any other mechanics; their wages vary from 5*s.* 6*d.* to 6*s.* 9*d.* per day. Fitters who can be trusted with engine repairs are not to be found, and, at present, have been difficult to be formed. All the waggon building, and the repairs, both of waggons and carriages, are executed by Europeans. Native painters are very scarce, and decidedly bad, with wages varying from 4*s.* 6*d.* to 9*s.* per day.

From this description of the capabilities of the native workmen, it will be readily understood, that foreigners must be imported for all the higher orders of work. It may be remarked, that Brazil supplies an immense number of young gentlemen of good family, and of good Brazilian education, who, in the absence of any other occupation, are anxious to get employment on public works; but although all are convinced that they know everything necessary to become 'administrators,' or 'superintendents,' they are found, on examination, to be wanting in all the essential requisites. As numerous applications for employment were received, advertisements were inserted in the newspapers, offering an engagement to any applicant who could draw, level, survey, speak or write English, keep accounts, or who had any previous experience on public works. During six years, there were not six applicants who could fairly comply with either of the terms of the requisition. As a consequence, all the foremen and most of the interpreters are English, as are also the engine-drivers, fitters, waggon-builders, painters, miners, platelayers, founders, horse-drivers, watchmen, and storekeepers. These are generally engaged for a term of years, at wages varying from £12 to £20 a month, their passage being paid out; they are also supported whilst sick, and sent home free if invalided.

As a rule, the native carpenter depends on his 'incho' for all work; but in and about the larger towns, sawyers are to be found, whose tools and mode of work are most amusing. Instead of the easy swing of the English sawyer, they jerk their little frame-saws up and down, with a good rest at the top and the bottom of the stroke. The result is very unsatisfactory; as the work comes from the saw rough, irregular, and winding, involving much labour before it can be brought into shape. Their wages are very high, and their habits uncertain, so that when there is a saw bench within 10 miles, their services on public works are not likely to be required.

The native Brazilian boys can swim and dive almost before they can walk, and amongst the men are everywhere to be found divers whose services may be made available in examining foundations and works under water. The rapidity with which they recover any small tool, bolt, or washer that has been dropped into the water is astonishing.

Pernambuco produces, in common with most of the provinces of Brazil, very superior timber, and of infinite variety; but as twenty trees may have to be cut down, and cleared away, before the one wanted can be obtained, and as there is a complete absence of roads, and of all ordinary means of transport, foreign timber is cheaper than native, at the sea-ports, and at all places at any distance from the forests. Again, the difficulty of transport leads to reduction in the length, and diminution in the scantling of native timber. At the same time the hardness of four-fifths of the native timber renders it difficult to work; whereas pitch pine, which is not subject to the attacks of the white ant, may be got from the United States, in any length, or scantling at a less price, and may be wrought with much greater facility. In the interior the use of native timber is compulsory, and there it can be obtained of good quality and of any scantling; but for particular qualities, such as large scantlings, or great lengths, the price rises. The most serviceable and most reasonable sizes are from 6 inches to 9 inches square, and from 25 feet to 40 feet long. These may be delivered at from 1*s.* to 1*s.* 6*d.* per foot, and if 10 inches, or 11 inches square, at from 1*s.* 6*d.* to 2*s.* per foot, whilst round timber, up to 10 inches diameter, costs about 6*d.* per foot. Accompanying this Paper are samples of upwards of one hundred kinds of timber, most of which would be available for temporary purposes, but not more than a score would do for any permanent work. According to the best local authorities, Maçaranduba (red), and Sapucaia (light red), are both very good woods, resisting the attacks of white ants, as well as the effects of wind, or water; Barubú (purple, hard) also possesses the same qualities. Sapucairano is lighter and not so good, but both it and Mangabevia de viado resist the white ant.

The mode of felling and dressing timber for the market is peculiar. In consequence of the difficulties of transport, the logs of timber are seldom rendered of a greater length than from 25 feet to 30 feet. The greater part, indeed, of the timber that is brought to the capital is considerably less, and is generally hewn out of the round to a scantling of from 12 inches by 6 inches to 16 inches by 8 inches, except at one end, where a bit is left on to which the rope is made fast, after being passed through a hole in the end of the timber; the use of timber hitches, or timber dogs, being quite unknown to the natives. Mr. Mansfield, one of the most intelligent writers on Brazil, referring to the enormous field open for mercantile speculation, proposes to construct rafts of timber, forgetting that nine out of ten of the species of woods will not float. The small quantities of durable timber now brought down the rivers, from the interior, can only be sent when the rivers are surcharged by the winter floods, and they are lashed to the jangada, or raft wood, previously referred to, to render the logs sufficiently buoyant.

There are besides numbers of woods valuable for dyeing purposes, and for furniture. The Paó d'Arco, besides being a useful timber for construction, forms one of the most attractive features of the Brazilian forests. There are several varieties, generally larger than the English elm, the place of leaves being supplied by bright beautiful blossoms, one kind being pink, another yellow, and a third violet. There is another tree the peculiarity of whose butt led the Author to send a sample to this country to accompany this Paper. One of this kind was measured giving a spread to the foot of 12 feet, and a height to the circular trunk of

20 feet, whence it ran up with very little taper and straight for a length of 70 feet without a branch, and then threw out its branches, showing a beautiful head about 30 feet higher.

There are but few varieties of native stone, and these are so difficult to obtain and to work, that Europe has heretofore supplied Recife with what is required. Thus from Lisbon is sent nearly all the ashlar dressings used in the public buildings, and in the best-finished private houses. The sandstone of the reef is not in general sufficiently durable for building purposes, even if it were not preserved by the authorities for the protection of the harbour. The island of St. Aleixo, on the coast to the southward of Recife, produces trap rock, and this has occasionally been brought up by small coasters to Recife. The same rock appears inland, adjoining the railway at Ilha, where a quarry has been opened and worked successfully. This stone was used for the tunnel fronts. Granite is to be found everywhere, and of every degree of hardness: in some few instances it has been found possible to make tolerable coursed work of it. The absence of limestone proper has been supplied by the use of coral, obtained from the reef on the coast. This is burnt for lime for building purposes, whilst shells from the beach, or oyster shells,[1] are used as a flux in the foundries.

The native bricks are of the rudest description, and are used in all stages, from the simply sun-dried to that of sound kiln-burnt; but so little pains are taken with the burning, that only about one-half those ordinarily sold are available for any work subject to much pressure, and even with the best the action of the atmosphere renders it necessary to plaster the whole surface exposed. When this is not done, the bricks moulder away, like badly-burnt bricks in England after a frost, leaving the mortar joints standing as a bead. The bricks are made by placing a couple of moulds, 12 inches by 6 inches by 2 inches, on the sanded floor of the brick shed, into each of which is thrown a lump of clay, trodden in by a boy. The surplus clay is then struck off, the mould removed, and the brick allowed to remain on the floor for a day, or two, when it is placed in stack ready for burning. When the railway works were commenced, an attempt was made to introduce the ordinary system of English brick-making; but although successful in a few instances the result on the whole was not satisfactory. A brick machine, by Messrs. Bradley and Craven, was subsequently sent out. It answered capitally, and turned out some first-rate bricks, upon which neither the weather, nor the atmosphere has produced any effect. From the general character of the buildings and the country, paving bricks are greatly used in Brazil.

The Brazilian, or Portuguese, tile is almost invariably used for covering roofs, and although attempts have been made to introduce corrugated iron and other materials for roofing, nothing is so good, where ventilation is so important, as the ordinary tile of the country; and as a rule, those who live with a tile over their heads dwell in a pleasanter atmosphere than the few who reside in rooms with ceilings. The place of the ordinary rafters for English roofing is supplied by what is called a 'caibro.' This is a straight stick of timber, forming the underwood of the native forest. These sticks are generally straight, and run to a height of from 30 to 40 feet, from 3 inches to 4 inches diameter. The lath is supplied by what is called the 'ripas,' which is reft off the outer part, or what is really the sapwood of one of the native trees, and is called 'emberiba.'

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[1] Oysters are found attached to the trees, on the river banks.

In addition to the building materials already alluded to, the country produces, for some miles round Pernambuco, and amongst the valleys and river beds, sand, which is available for ballast; but no gravel is to be found in that part of the province traversed by the railway.

The materials required to be imported into Brazil for the construction and carrying on of public works are iron for rails, chairs, bridges, rolling stock, and repairs; steel, coke, and coal; glass, oil, turpentine, tallow, tools, doors, windows and general stores.

Reference has been made in the early part of this Paper to the want of all statistics in the province, and to the difficulty of obtaining information. The Author thinks it right, therefore, to say he is indebted for the data as to the harbour, roads, &c. about Recife, to Mr. W. Martineau (M. Inst. C.E.), Government Engineer and Director of the Public Works of the Province. Those relating to the railway have been supplied by Mr. John Whitfield, the representative in Brazil of the Engineer-in-chief, during his absence, Mr. James Fforde, the Resident Engineer, and Mr. G. O. Mann, the Locomotive Superintendent.

In Appendix A. will be found a list of the standard dimensions of the Recife and São Francisco Railway, and of the principal structures upon it, of many of which, as well as of the rolling stock, drawings and photographs are exhibited.

Appendix B. contains a table of the wages of the different classes of labourers and artizans.

Appendix C. gives the prices of materials, and of the cost of various kinds of work and of transport; whilst a numerous collection of samples of building materials and geological specimens is shown.

Appendix D. shows the actual cost, per mile per annum, of the maintenance of the way and works of the Recife and São Francisco Railway, on an average of four years.

[APPENDIX

APPENDIX (A.)

Some trouble has been taken to secure uniformity of dimensions throughout the Recife and São Francisco Railway, and the following general results have been arrived at:—

	Ft.	In.
Gauge of line	5	3
Middle space	7	6
Cuttings (viz., formation width 16 ft. + 2 ft. + 2 ft. drains)	20	0
Ditto in rock	10	0
Embankments, formation width	16	0
Ditto, above the flood level	1	6
Bridges, minimum headway	14	6
Ditto ditto width	14	0
Tunnel, minimum headway	14	6
Ditto ditto width	16	0
Station platforms, above rails	2	3
Ditto, clearance from ditto	2	9

CARRIAGES AND WAGGONS.

All the wheels and axles are uniform, the waggons being provided with buffers and spring drawbar, and the tyres of the wheels being of Low Moor iron.

	Ft.	In.
Diameter of wheels	3	6
Distance from centre to centre of wheels	9	10
Length of axles to centre of journals	7	1½
Length of journals	0	8
Diameter of journals	0	3¼
Height of buffers	3	4
Distance between the centres of the buffers	4	6
Carriage, width of roof	12	0
Ditto ditto body	9	0
Ditto ditto steps	10	6
Turntable for engine and tender	42	0
Ditto for carriages	15	0

LOCOMOTIVE ENGINES.

	Ft.	In.
Diameter of cylinder	0	14
Length of stroke	0	20
Diameter of coupled wheels	5	6
Ditto of leading ditto	4	0
Distance between the coupled wheels	7	5

APPENDIX (B.)

TABLE OF WAGES.

	s.	d.		s.	d.	
Native labour, before the railway works began	1	4	to	2	3	per day.
„ shortly after ditto	2	3	„	3	0	„
„ when the works were in active progress	3	0	„	3	9	„
„ at present, and for the past year	2	3	„	3	0	„
Native, or Portuguese Gangers	4	6	„	9	0	„
„ „ Timekeepers and clerks	6	9	„	9	0	„
„ „ Carpenters	4	6	„	5	6	„
„ „ Woodsmen	3	9	„	4	6	„
„ „ Bricklayers and masons .	4	6	„	6	9	„
„ „ Smiths	5	6	„	6	9	„
„ „ Strikers	3	0	„	3	9	„
„ „ Fitters	6	9	„	9	0	„
„ „ Turners						
„ „ Painters						
English Sailors	4	6	„	6	9	„
„ Foremen	13	6	„	18	0	„

English workmen are usually engaged for three years, at a salary rising each year; their passages being paid home on the expiration of their engagements, or if invalided before that period.

Watchmen, stable-keepers, and horse-drivers .	£ 8 to £10	per month.
Smiths, carpenters, bricklayers, and masons .	£12 to £14	„
Foremen, platelayers, and engine-drivers . .	£14 to £16	„

APPENDIX (C.)

PRICES OF MATERIALS.

Native.

		£.	s.	d.		£.	s.	d.
Timber delivered at the workshops on the line	per cubic foot.	0	1	3	to	0	1	9
Caibros	each.	0	0	9	„	0	0	11
Ripas	per 100.	0	6	9	„	0	9	0
Rough logs, for sleepers, not sawn, 9 feet long and 12 inches diameter	each.	0	3	3	„	0	4	0
Bricks, hand-made	per 1000.	3	0	0	„	4	10	0
Ditto, machine-made.	„	2	0	0	„	3	10	0
Ditto, paving	„	5	0	0	„	5	10	0
Burning bricks, fuel only	„	0	9	0				
Tiles	„	3	10	0	„	6	0	0
Lime	per alqueire.	0	1	3	„	0	1	6
Building stone, exclusive of carriage . .	per cubic yard.	0	6	9	„	0	8	6
Iron castings at the foundry, in Recife .	per cwt.	1	8	0	„	2	10	0

Foreign.

		£.	s.	d.		£.	s.	d.
Pitch pine, from the United States. . . .	per cubic foot.	0	2	3	„	0	2	9
Baltic yellow deals	„	0	2	6	„	0	3	0
Coal	per ton.	1	16	0	„	2	5	0
Coke	„	3	0	0	„	5	0	0
Oil, rape	per gallon.	0	5	8				
Tallow	per cwt.	2	14	0				
Turpentine	per gallon.	0	3	5				
Waste	per lb.	0	0	3				

COST OF WORK.

		£.	s.	d.		£.	s.	d.
Earthwork, ditches	per cubic yard.	0	0	8	to	0	0	11
„ getting and filling waggons	„	0	0	8	„	0	0	11
„ in foundations	„	0	0	11	„	0	1	1½
„ „ if run 50 yards	„	0	1	1½	„	0	1	4
„ rock, exclusive of powder and drills	„	0	6	9	„	0	9	0
Brickwork in heavy abutments	„	0	10	0	„	0	11	0
„ in walls, from 18 inches to 2 feet 6 inches thick	„	0	11	0	„	0	13	6
Masonry in abutments	„	0	9	0	„	0	10	0
„ in walls, 2 feet thick	„	0	10	0	„	0	13	6

COST OF TRANSPORT.

		£.	s.	d.		£.	s.	d.
Four bullocks and man and boy, from the workshops to the wood, about 2 miles	per trip.	0	11	3				
Bullock-cart, with three pairs of oxen, carrying from 15 to 20 cwt., going about 10 miles per day	per ton per mile.	0	5	0				
Bullocks for draught purposes	per day.	0	9	0	to	0	12	0
Pack-horses, carrying from 256 lbs. to 320 lbs.	„	0	6	9	„	0	8	0
Sawing timber, hard or soft	per 100 feet.	0	4	6	total	0	9	0
Loading, unloading, and shop expenses	„	0	4	6				
Building covered goods-waggon, complete	..	22	10	0				
Sawing timber for goods-waggon, painting, wheeling, &c.	..	11	5	0				
Labour in making barrows, complete	each.	0	6	9				
Permanent way, cost of laying	per lineal yard,	0	1	9	to	0	2	3
„ lifting, boxing, straightening	„	0	1	0	„	0	1	3
Laying points and crossings	..	8	0	0	„	11	0	0

APPENDIX (D.)

Cost of the Maintenance of the Way and Works of the Recife and São Francisco Railway, per mile, per annum, on an average of Four Years.

			£.	s.	d.
Repairs of permanent way, lifting, packing, &c.,	per mile	per annum	158	10	1
Ballast, and purchase of gravel	„	„	1	5	11
Repairs of bridges, culverts, tunnel, &c.	„	„	0	7	10
„ stations and appurtenances	„	„	12	7	11
„ signals and waterworks	„	„	0	0	3½
„ gates, fences, and ditches	„	„	5	19	3½
Salaries of engineers, and inspectors, with office expenses	„	„	39	12	0
Total average cost per mile per annum			£218	3	4

[Mr. Peniston

Mr. **Peniston** said, he was glad to avail himself of the opportunity that was afforded him of collecting a few facts for the information of the Institution. Although physically unable to take part in the discussion himself, fortunately those who had assisted in the collection of the facts were present, as were also the representatives of several large establishments connected with works in Brazil, who were well qualified to take part in any discussion that might arise. He should also be happy to supply any further particulars which it might be in his power to do.

Mr. E. **De Mornay**, as one of the Concessionaires of the Pernambuco (Recife and São Francisco) Railway, would avail himself of this opportunity to state, although he had not then with him the details of the survey, so as to enable him to give the exact length of the lines to which the estimates referred, that the line estimated by Mr. Borthwick was divided into four sections, and that the estimate of the concessionaires related to the first three sections only. The concessionaires considered, a railway might be made in Brazil upon the American principle, involving only a moderate outlay, with immense advantage to that country; and although it had not been carried out upon that principle, he wished to explain why they had advocated that view. In the first place a return of 7 per cent. was, during construction, to be secured to the shareholders; and it was thought as that guarantee of interest was made good at the expense of the shareholders' capital, it would be of great advantage that the line should be cheaply constructed, and that the works should be completed within the shortest period of time. Instead of that the line had been many years under construction: and it was for those who were more able to do so than himself, to calculate how far the capital subscribed for the railway ought to be expended in the payment of interest to the shareholders. Under those circumstances it was considered important by the concessionaires, that the line should be made at a low cost. It had always appeared to him, that an expensive railway in a country like Brazil would be a calamity rather than a benefit; and in his opinion the only lines that could return a fair interest to the shareholders, and conduce to an extension of the railway system in Brazil, would be those which were constructed at a moderate amount of expenditure.

Mr. C. B. **Lane** said, so many topics had been referred to in the Paper, that it was difficult to speak upon them without previous consideration. He would, however, in the first place allude to the question of the employment of native timber. When he first went to Brazil, about ten years ago, as the Government Engineer, he made a point of studying carefully the various building materials of the country; and the conclusion he arrived at, after two, or three years, was, that if railways were to be constructed in that country, upon the alleged economical principle of using the native timber, as it was found, it would be better not to make them at all. Timber employed in railway bridges and in viaducts was destroyed so rapidly, in that inter-tropical climate, that their maintenance and renewal would more than eat up the receipts which should go to diminish the onus of the Government guarantees. Although he fully agreed in the advantages of reducing the first cost, yet economy was a relative term. The first railway in Brazil was opened in 1854. It was a short line, leading from Mauá, in the Bay of Rio de Janeiro, to the foot of the great 'Serra' of Petropolis. It passed for a considerable part of its length over a low muddy swamp, full of mangroves—a most uninteresting spot, the only thing to enliven the scene being an occasional alligator. Various water-courses were crossed, for which timber was employed; the best timber no doubt available, at that time, having been selected for the purpose. About two years after that line had been opened, he inspected the water-passages and bridges: for after that short time it had become necessary to rebuild them with other materials. He could not more graphically describe the condition of the timber, than by stating that in one case upon giving a transom under the railway a moderate kick, his foot was buried in it up to the instep. With the timber in that condition, after two, or three years, it was manifestly better not to make railways than to use such materials in their construction. He did not doubt, that in Brazil there was a great abundance of valuable timber: but as yet there were no certain means of getting at that timber, or being sure of its quality and properties when it was obtained. There was also abundance of gold, copper, and other valuable minerals in that country; but the time had not yet arrived when they could be made available. It was the same with regard to the timber. It would be cheaper to send from Brazil to Liverpool for a stick of timber, even though it was first imported from America to Liverpool, than to cut one in Brazil half a dozen miles from where it was required to be used. All the timber he had seen in Brazil—though good for many other purposes—was inapplicable for railway sleepers; the quick-growing woods being too perishable, and the hard woods too brittle. There was a specimen of timber upon the table which felt like a piece of porcelain, and yet after five years' immersion in the waters of Rio Bay it was completely riddled by the teredo. It was totally unfit for railway sleepers, being too brittle. On an inspection he made of the Pernambuco Railway, three years ago, he found that the wear and tear of the imported creosoted sleepers on the first section had not amounted to more than about 1 per cent. during the two years that the line had then been open for traffic. He could not state exactly the amount of depreciation of the sleepers of native wood laid on other sections of that line; but from what he saw he had no doubt it would turn out to be equal to that which was stated in a Paper by Mr. M'Master[1] read before the Institution a short time ago, to have occurred from using native timber on the Madras Railway,—that was, to 33 per cent. in the first year, or two. This in the matter of sleepers was a very heavy item in the maintenance of a railway of small traffic. On the Bahia Railway it was stipulated in the concession that only native timber should be employed: but very soon after the works were commenced, it was found impossible to procure suitable native timber for sleepers: upon which the Engineer, Mr. Vignoles (M. Inst. C.E.), and the Company petitioned the Government to have that particular clause of the concession altered: and under his (Mr. Lane's) advice it was altered, and creosoted North of Europe timber was substituted. He had given that advice in the full belief, that there was great difficulty in finding proper native timber, and also that the creosoted timber offered as a substitute was a very superior material. In advocating his views relating to the employment of other material than native timber in bridges and viaducts, he had encountered much opposition from parties interested in the execution of some of the lines of railway; but he had ultimately succeded in having the correctness of these views duly recognized, and the rule now was, that all such railway structures should be constructed of "stone, brick, or iron, singly or combined." Greaves' 'pot' sleeper had been introduced on about 10 miles of the Pernambuco line. It was also used on the Mauá Railway, and was being employed by Mr. Brunlees (M. Inst. C.E.) on the San Paulo line. He believed it would be found to answer well in Brazil, India, and in other inter-tropical countries, with the present amount of traffic; but he felt convinced that if the time ever came when such heavy trains were run and at such high velocities as prevailed in England, the iron 'pot' sleeper would have to be relinquished, as it was too rigid for high velocities.

The labour question was no doubt a very important one. As far as his own experience went, he thought, under the best circumstances, it would be found that the labour of Europeans in an inter-tropical climate was very nearly that determined many years ago by the well-known French philosopher and Engineer officer Coulomb, who in employing French Sappers and Miners in the Island of Martinique, where the thermometer was seldom below 77°, and similar troops in France, stated the efficiency of their labour to be less than one half in the tropical climate: and in the inter-tropical portions of Brazil with which he was acquainted, the thermometer was seldom below 77° during the day.

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[1] *Vide* ante, page 241.

With regard to the mason work, his own experience (which was chiefly at Rio de Janeiro) differed from that of Mr. Peniston. In employing Portuguese, as masons, the work was done extremely well, and he had rarely seen men work a quoin more truly; but they were slow as compared with English workmen, in England. The worked stone brought from Lisbon, referred to by Mr. Peniston, must he thought be only that for ornamental purposes, because the neighbourhood of Lisbon supplied beautiful marble which was not found in Brazil.

Mr. James T. Wood remarked, that the engineering part of the subject had been so fully discussed in the Paper that he would not further touch upon it. He would therefore direct attention to a few circumstances, which five, or six years hence would be more interesting than they were at the present moment:—that was to the development of the traffic of a country where land was of small value, and where labour was scarce—to trace what would be the result in a few years of increased facilities of transit throughout the country. One great result he thought would be, the bringing of the population and the changing of estates, to localities in the immediate vicinity of the railways, in consequence of the proprietors of slave labour migrating, and clearing the lands adjoining the line, in the same way as the borders of navigable rivers, in all parts of the world, had been selected for cultivation. When he was in Brazil he took a journey of above 70 miles from the coast. He there met a most intelligent man, the schoolmaster of the district, who gave a history of the large number of farms and estates that had been brought into cultivation, by cutting down the trees in the neighbourhood of the line, and in anticipation of the present terminal station. He thought that five, or six years hence, if the statistics could be obtained, they would be of great interest, as showing the movement of the population towards the localities where improved means of communication were provided.

Another point, which was a most material one, was that which had reference to labour. As far as his experience went, a labourer who could read and write was very scarce in the Province of Pernambuco. During the period of slavery there, certain acts of labour were performed solely by slaves, even down to the carrying of a parcel; and the main distinction between the people was those who were slaves, and those who were not, the latter being too proud to do slave work. The railway was consequently deprived of the useful class of men from which the porters in this country was obtained. During the last twenty years that feeling had been going out, and in the course of time it might be possible to find intelligent men amongst the labouring classes of the country, who could read and write, and whose services would be of the greatest value to the country. It was his opinion, that the gradual extension of the line, say at the rate of 20 miles a year, might be executed. But it was of importance that the surveys and the exact direction of the extension should be judiciously and accurately prearranged, so as to give time and opportunity for the adjoining land to be brought into cultivation, during the progress of the railway works. He also considered there was ample field for branch feeders to be made; but as the traffic on these branches could not pay any company an adequate return for the capital expended, they should be made at the expense of the proprietors whose estates would be benefited. He was happy to bear testimony to the excessive kindness and hospitality to Europeans, which prevailed all over the country.

Mr. E. B. Webb said, about three years ago, he had the honour of reading a Paper before the Institution, "On the Means of Communication in the Empire of Brazil,"[1] and he referred, in that Paper, particularly to the use of timber, and to the cost of labour upon the works. Since that time professional engagements had caused him to revisit South America. He had traversed the greater part of the eastern coast of that continent, and had visited all the railways which were in course of construction. The opinions he expressed three years ago in reference to Brazilian public works had been confirmed. He had an opportunity of inspecting timber structures, which, when he left Brazil, in 1858, were apparently in a sound condition, and he found them, last year, in ruins. The specimen of timber laid on the table by Mr. Lane, was a portion of a pile driven under his direction in the Bay of Rio de Janeiro, in 1854. That piece of timber was removed about the year 1858. It was a fair sample of the material in a pier of some magnitude; and the destruction caused by the 'teredo' was complete. He had no hesitation in saying, that all timber, taken in large quantities from the forests of Brazil, and driven in the littoral waters of that country, would, in a short time, be reduced to a similar condition.

With reference to sleepers of native timber, he was of opinion that, on the ground of economy and convenience, their use was most imprudent; because scarcely any timber, that could be obtained in sufficient quantity, size and condition, would endure the wear and tear of the climate much longer than two years. The loss and annoyance resulting from an early decay of sleepers, would be felt by the Companies and not by the contractors. In the Brazilian forests there were countless varieties of timber, and specimens might be produced by the hundred; but the difficulty of selecting, collecting and transporting to the works a sufficient supply of durable timber, could only be correctly estimated after an experience in the country itself. The forests of Brazil, unlike pine forests, never presented a number of trees of the same description in one spot; and serviceable timber was very limited. It was frequently necessary to make a selection of one tree only in the midst of several hundreds of no value whatever. In fact an Engineer, standing in the magnificent primeval forests of Brazil, might paraphrase the words of the Ancient Mariner, and exclaim—

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xix., p. 240.

> "Timber, timber everywhere,
> And not a stick to use!"

When visiting the Brazilian railways last year, he was sorry to find that native timber was being largely used as sleepers. He saw, for instance, on the San Paulo Railway, large piles of native timber sleepers. These sleepers were made up of many varieties of timber, more or less durable; they were of irregular scantling, and being exposed to the sun and weather, they were splitting freely. He believed that the greater part of those sleepers, after being down for two years, would be found to be decayed; and long before the lapse of two years the spikes would become loosened, on account of the tendency of the timber to split. The result of his experience, in the use of timber in Brazilian soil, made him regard its employment as something like putting "ashes to ashes." He knew of no instance of any attempt to creosote the native timber, which, when worth anything at all, was hard, and had a tendency to split. On the same railway timber telegraph posts were being erected. Now he knew for a fact, that on the Dom Pedro Segundo Railway (Rio de Janeiro) three several sets of timber telegraph posts had been put up; and the Company, after having incurred very great expense and annoyance, were now erecting posts of iron, notwithstanding that their line passed through some of the most magnificent forests on the face of the globe. Considerable experience induced him to draw the general conclusion, that the use of native timber sleepers in all such countries as Brazil, was very unadvisable, first on account of the difficulty in selection, and secondly on account of the trouble and expense in keeping the permanent way in a proper state of repair. In such countries, for years to come, high velocities would not be required; and with moderate speeds iron sleepers were safe and economical, and they might be considered as indestructible.

Mr. F. W. SHEILDS said, four, or five years ago he went to Brazil to lay out works of some magnitude. At that time he inspected the works on the Pernambuco Railway, with the view of applying the experience gained upon that line, to a railway at Bahia, then about to be commenced. The conclusion he came to was, that all works of art in Brazil would be more safely estimated and more satisfactorily carried out, upon the supposition that the materials should be designed and be prepared in

England, in such a manner that they could be put together, with the least trouble and labour, after their arrival in Brazil. He was led to this conclusion, not only on account of the perishable nature of the timber, and the generally inferior quality of the masonry, but also because, in a hot climate, little reliance could be comparatively placed upon the labour of even the English workmen sent out there, as their nervous system was generally debilitated by the effects of the climate. It was therefore far safer, as a general rule, to design works of art, in the simplest form, with English materials and have them erected in the country, no matter in what part it might be. He might add, that in the course of his explorations, he examined some rude bridges which had been erected about three years, and on breaking the surface of the timber, which he could easily do with his foot, he found the interior of the timber filled with white ants. This satisfied him that the use of native timber was generally to be avoided in permanent works. With regard to iron work, it appeared to him, that the use of corrugated iron, so much employed here for roofing, would in a country like Brazil be a great mistake. The native tiles laid upon the rafters, with no ceiling underneath, formed the best kind of roofing for that country, as, although it made a heavy roof, it was not only the best protection against the heat of the sun, but it also afforded the best means of ventilation. In a large railway viaduct, which had been intrusted to him to design, and to arrange for the execution of, cast-iron piles were required to be used, at a considerable depth in sea water. It was for some time a question, whether the salt water and other elements would not have a very deteriorating effect upon the cast iron; but he had recently received a report stating, that immediately upon the iron being put down into the water, it became so thickly encrusted with marine shells, as to form a complete protection against the action of the salt water, so that there was every probability that these cast-iron piles would endure for a long period. In using wrought iron, in situations exposed to the atmosphere, in these climates, care must be taken effectually to protect it, by thorough painting. Such a construction as a bridge, with wrought-iron girders, must be constantly painted and carefully protected from the influences of the climate, which possessed the peculiarity of an excessive degree of heat, combined with much moisture, the corroding effects of which, upon wrought-ironwork, were remarkably rapid.

Mr. J. **Whitfield**, in reply upon the discussion, for the Author, said with regard to timber, there was a great variety of wood in Brazil which would be useful and would endure for a long time under any circumstances; other descriptions under the most favourable circumstances would not endure for twelve months. There were some varieties of timber the outside of which was exceedingly perishable, but the interior would last for a long time. He had known instances of timber, which had been in use for fifty years, both in and out of water. That was proved to be the case in some old buildings he had examined; and he found that some descriptions of timber would last sound for a long time. It was quite true that wrought iron when put under sea water rapidly became encrusted with marine shells, which protected it to a great extent: but wrought iron when exposed to the atmosphere, near the coast, if not kept well painted, was very quickly corroded and destroyed. In the interior of the country, where the atmosphere was drier, ironwork properly painted would last as long, if not longer, than in England. It was a great mistake to suppose that the whole of Brazil was like that part of the country, near to the sea-coast. The hygrometric state of the atmosphere had a powerful effect upon materials near to the coast; but it was different in the interior. Some materials of construction might therefore be usefully employed in one situation, which would perish rapidly in another locality.

March 31, 1863.

JOHN FOWLER, Vice-President,
in the Chair.

No. 1,082.—"Structures in the Sea, without Cofferdams; with a Description of the Works of the new Albert Harbour at Greenock." By Daniel Miller.

Of late years a revolution has been going on in nearly all the branches of engineering practice. The application of scientific principles, the adoption of new constructive materials, and the development of modern wants, by the expansion of trade and commerce, have in some cases much altered the formerly received modes of construction, and in others rendered necessary the introduction of entirely novel methods.

Although harbour and dock engineering has participated in this change, there is no doubt still scope for improvement, in the scientific and economical construction of these works. And when it is considered how much the prosperity of a great maritime and commercial country depends upon the extent and efficiency of its docks and harbours, few subjects are deserving of greater attention.

The more immediate object of this Paper is to treat of the various methods of constructing the foundations of quay-walls, piers, or breakwaters, for the formation of docks and harbours in deep water; to describe works of this kind carried out on principles different from those usually practised; and to point out the further application of these principles to other works of a similar nature.

The formation of these works has usually required the adoption of very expensive means; and an easy and economical mode of building such structures, so as to combine the various conditions necessary to insure solidity and capability of resisting the mechanical forces to which they are subjected, and also the destructive action of exposure to the elements, the boring of marine worms, or the corrosive action of salt water, has been hitherto a desideratum.

Several methods of founding works in deep water are at present practised; but there are objections to most of these systems, arising either from their expensive nature, or from defects in the durability of the structures. The plans which have chiefly prevailed are—

Founding on piling carried up to about the level of low water;
Constructing within caissons or cofferdams; or,
Building under water by means of diving apparatus.

The first method has serious defects, both in deficiency of strength and of durability, as the piling is often insufficient to resist the lateral pressure from behind the wall, and the heads of the piles being exposed to the alternate action of air and water soon decay, when the weight of the wall above rapidly completes the failure of the whole structure. Of course where there are marine worms this mode is quite inapplicable. Instances of the failure of such works will occur to many. Referring to the River Clyde, for example, nearly all the older quay-walls of the harbour of Glasgow were built on this principle, and have given way from the decay of the piles, or have required very expensive repairs to keep them up; and at Port Glasgow Docks, the walls, which were also built on that system, gave way from the lateral pressure forcing them out, shortly after completion, greatly to the injury of that port.

The most usual mode adopted, where works of great solidity are required, is to resort to cofferdams, and to pump out the water from the enclosed space, so that the foundations and the walls may be constructed as on dry land. This is certainly most effectual, but it is at the same time generally expensive, and it is often not unattended with danger. In many cases, too, from the nature of the strata, it is almost impossible to form an effective cofferdam. The construction of cofferdams, moreover, frequently requires great engineering skill, besides involving vast expense; and when it is considered that they are only wanted for a temporary purpose, t must be conceded that it is an object of great importance, to devise some mode by which their use can be obviated, and solid and durable works can be executed without their aid.

The system of building under water by means of diving-bells and diving-dresses has been practised to a considerable extent, and the improved apparatus now used gives great facilities for this kind of work; but it is only applicable under particular circumstances, and it is also costly, besides being liable to cause delay in the progress of the work. The Dover Breakwater, at present in course of construction, is an example on a large scale of this mode of construction, but it is also an instance of the vast sums which may be expended on this system.

In bridge building, a great innovation has been made in the construction of the piers without the aid of cofferdams, and the

French engineers have been, until lately, in advance in this mode of constructing such works. The plan they pursue was introduced by Vicat in 1813; it consists in forming enclosures of close piling, or 'caisses sans fonds,' of the shape of the pier, up to about low-water level, and filling in with hydraulic concrete, or béton, on which the upper part of the piers is built in the usual manner. Some important bridges in France, and many of those across the Seine at and near Paris, such as the Carrousel, Jena, Austerlitz, Alma, and Asnières, have the piers formed in this way without cofferdams. These works of the French Engineers, however, being in some instances a combination of timber and concrete, cannot be said to possess substantiality and durability, and a change was necessary, in order to enable them to compete with stone structures built in the usual manner. The modes recently adopted in constructing the piers of the Westminster and the Chelsea Bridges without cofferdams, have effected this, and these works are instances of successful departure from stereotyped rules, and of the application of scientific principles in the practice of bridge building.

APPLICATION OF CONCRETE.

In these modes of construction, béton or hydraulic concrete has played an important part, and it also forms a leading feature in the plans for marine works afterwards to be described.

This valuable compound, though employed in Roman and mediæval times, was allowed to go out of use, and since then, it has not, until recently, been much recognised as a constructive material by the Engineers of this country, who have, for marine purposes, placed their faith chiefly in works of cyclopean masonry, constructed within cofferdams, or built under water by the diving-bell. The French Engineers deserve the credit of having been, for a longer period in modern times, alive to the value of béton, as an important auxiliary, in hydraulic works.

For some time, however, its value has been more appreciated in this country as a substitute for masonry, and it has been employed in some important works. Still, its use is chiefly confined to forming a homogeneous and monolithic bearing stratum for foundations, and not, properly speaking, as a constructive material, to which latter purpose it is more especially the Author's object to direct attention. In particular, there are but few examples of the application of liquid concrete, deposited and allowed to set in the water, in the construction of submarine works.

There are three modes in which concrete may be applied for constructive purposes,—building it in mass, and allowing it to set before water has access to the work, as has been adopted in the construction of the walls of the Victoria Docks, by Mr. Bidder, and in those of the London Docks, by the late Mr. Rendel; preparing it first in blocks, and allowing it to harden before being used, as employed by the late Mr. Walker at the Dover Breakwater, and by Mr. Hawkshaw for the new sea forts, for protecting the arsenals of Plymouth and Portsmouth; and depositing it in a liquid state, and allowing it to set under water, as practised upon a gigantic scale by M. Noël, in the construction of the large government Graving Docks at Toulon. In the latter case hydraulic concrete has been deposited in a liquid state, in the sea water, at a depth of about 40 feet, forming a vast rectangular trough of béton about 100 feet wide, of the length of each dock respectively, and with walls and bottom about 16 feet thick. After the béton had set, the water was pumped out from the interior, an inner lining of masonry to form the altars, stairs, and floor was built, the caisson put into its place, and the concrete side of the trough at the entrance having been removed, the dock was complete.

The facilities for making béton or hydraulic concrete, which has the invaluable property of setting under water, and of thus forming an artificial rock or stone, are very great; as it may be formed either from the naturally hydraulic limes, the artificially hydraulic limes or cement, or from the rich or non-hydraulic limes, rendered hydraulic by the admixture of other substances, such as pozzuolana, minion, or iron-mine dust.

The béton made from the naturally hydraulic limes, which are found extensively in this and other countries, is the most to be depended upon. The blue lias in England, the limestone of Arden (found near Glasgow) in Scotland, and that of Theil in France, are good specimens of their kind, possessing in an eminent degree the property of setting under water. Of the Arden lime, the Author and his partner have had abundant experience, in the dock works at Glasgow, Greenock, and other places. As to the blue lias, its extensive employment in the docks at Liverpool, London, and other important works throughout the kingdom, is proof of its good properties. The hydraulic limes of France have been still more severely tested, by their application for the formation of the large concrete blocks, used for the protection of the seaward side of the French breakwaters. It may be useful to mention, for comparison, the proportions of some of the concretes made from these various limes. The Arden lime concrete, employed by Messrs. Bell and Miller for the foundations of the large Graving Dock at Glasgow, was composed of one part of ground Arden lime, one part of iron-mine dust, one part of sand, and four and a half parts of gravel and quarry chips. The lias concrete, used at the recent extension of the London Docks by Mr. Rendel, consisted of one part of blue lias lime to six parts of gravel and sand. The proportions adopted for the blocks of the Mole at

Marseilles, were two parts of broken stones to one of mortar, the latter being composed of three parts of Theil lime to five of sand.

A knowledge of the mode of composing artificial hydraulic limes is of great importance, in situations where natural hydraulic limes are not easily procurable. Smeaton was the first to point out, that it was to the clay or silicate of alumina in the composition of the hydraulic limes, that they were indebted for their peculiar property. . Subsequently the able researches of Vicat showed, by actual experiment, how all the rich or non-hydraulic limes might be rendered eminently hydraulic, by burning them with a certain proportion of silicious clay. Indeed, to Vicat is due the credit of having reduced the knowledge of limes to a system, and of having shown the practical application of concrete as an eminently constructive material. The excellent artificial cements now manufactured are most valuable to the Engineer; and the concrete made with Portland cement can hardly be surpassed. That used at the new Westminster Bridge, is harder and more compact than the greater number of building stones, even where put down in the bed of the Thames, and where it is exposed to the running stream. Portland cement concrete is also extensively used for the artificial blocks, weighing from 6 tons to 10 tons each, which form the hearting of the breakwater at Dover and that at Alderney, the proportions being one part of cement to ten parts of shingle.

Some substances, such as pozzuolana—a volcanic production found chiefly in Italy—have, in consequence apparently of silicate of alumina being predominant in their composition, the property of giving hydraulic qualities to the rich or non-hydraulic limes. It is of these that the concrete is made, which has long been used for marine works on the shores of the Mediterranean; and, indeed, the piers at some of the Italian ports have been constructed almost entirely of hydraulic concrete. The Author had lately an opportunity of examining, at Genoa, the extension of one of the moles of the harbour, the inner side of which has a vertical wall. The latter was in process of being constructed under water entirely of pozzuolana concrete simply thrown into the sea, from baskets carried on men's heads, a boarding confining it to the shape of the wall. In a short period, it set quite hard, so as to enable the upper part of the wall, which is of stone, to be built upon it. The outer side of the mole, which had been previously made, was formed by stones deposited 'à pierre perdue.' Though the depth of the quay wall was not great, this shows the confidence which the Italian Engineers have in concrete applied under water in a soft state. The piers of the new basin constructed by the Austrian Government at Pola, in Istria, are also formed, in a similar manner, of concrete confined between rows of timber piling.

But perhaps the most striking application on a large scale of pozzuolana concrete, is in the great mole which protects the port of Algiers. To form the mole, blocks of béton of immense size, so as to be immoveable by the force of the sea, were employed. Some of these were formed in situ, by pouring the concrete into large timber cases without bottoms, sunk in the sea in the line of the mole. Other blocks of a smaller size, though upwards of 30 tons in weight, were made on shore, being moulded in strong wooden boxes. After the béton had set, the boxes were removed, and the blocks were launched into the sea to find their own level. The béton for the blocks in situ was composed of one part of rich lime in paste, two parts of pozzuolana and four parts of broken stone; that for the blocks made on shore, was formed of one part of lime in paste, one part of pozzuolana, one part of sand, and three parts of broken stone. These blocks set sufficiently hard in twenty-four hours, to resist the shocks of heavy seas, and the mole now stands firmly, instead of being, as it was when formed of loose blocks of stone in the time of the Moors, nearly destroyed every winter.

The French Engineers have shown great boldness and skill in the application of béton, as exemplified in the Pont de l'Alma over the Seine, the arches of which, as well as the piers, are formed of rubble concrete; in the new Graving Dock at Toulon, before alluded to; and in the formation, or protection of breakwaters, by enormous artificial blocks of béton, as carried out at Marseilles, Cherbourg, La Ciotat, Cette, Vendres, Cassis, and Algiers. A short time ago, when the Author inspected the mole, or breakwater which encloses the Harbour of Marseilles, he found the huge rectangular concrete blocks, weighing upwards of 20 tons each, by which its seaward side is protected on the 'pierre perdue' principle, perfectly entire and sharp in their outline, though they had been exposed for many years to the action of the sea. Any one standing upon that mole, and witnessing in a gale the heavy seas breaking with tremendous force on these concrete masses and recoiling harmlessly, could have no doubt as to the efficiency of concrete as a constructive material.

Hydraulic concrete, to be effective, requires care and attention in its manipulation, and in the regulation of the proper proportions of its materials. Any failures must have arisen from inattention to these, or similar points, as there is ample experience to show that, when properly made, every confidence may be placed in its strength and durability. Even where stone is abundant, this material may be often employed with economy and advantage; but where stone cannot be obtained, the importance of being able to form an effective substitute, out of materials of so little value, and so widely distributed, can hardly be overrated.

CONSTRUCTION OF DOCK AND QUAY-WALLS WITHOUT COFFERDAMS.

Though so much has been effected in bridge building, little has yet been done in founding and constructing quay walls, piers, or breakwaters in deep water, of a solid and durable character, without the aid of cofferdams, diving apparatus, or other means equally expensive. The Author has, for a considerable period, devoted his attention to this subject; but it is only recently that he has had a favourable opportunity of putting his ideas into practice upon a large scale.

In sea water the Engineer has to encounter enemies which do not exist in fresh water, or at least only to a trifling extent. The 'teredo navalis' and other worms, quickly destroy timber, and the corrosive action of the sea water, and other peculiar properties, have a prejudicial effect upon iron. In consequence of these deteriorating influences, these materials have not hitherto been much employed in sea works, where durability is essential. There is no doubt, however, that they may be employed with advantage, if protected from the destructive action alluded to; and whatever materials may be used, it is desirable that the surfaces exposed to the sea should be of continuous stone work, or other material capable of resisting its effects.

As Engineers-in-chief for the Albert Harbour at Greenock, the Author, and his partner Mr. Bell, have had an opportunity of introducing the new system there adopted for the construction of sea-walls and quays in deep water, without the aid of cofferdams, by which a large saving is effected, and works of great solidity and durability have been secured.

The accommodation for the loading and discharging of the shipping of Greenock consists of three open tidal docks or harbours, the most recent having been constructed by the late Mr. Locke, M.P. Extensive schemes for wet docks have been proposed at different times by several Engineers, particularly by Rennie, Telford, and Walker and Burges, but hitherto, no wet docks have been constructed, as it has been considered that the moderate range of the tide—from 8 feet to 10 feet—does not render them indispensable, and the trade is found to be efficiently worked by the present system. In the additional accommodation in progress, the system of harbours is adhered to, though provision is left for conversion into wet docks, by the addition of locks and gates, should this at some future period be deemed advisable.

The new works (Plate 9, Fig. 1) are situated on the west side of the town, and in order not to interfere with valuable shore ground, they have been projected almost entirely beyond the high-water line into the sea. The depth of water at the outer line being considerable, the amount of excavation required in the interior is comparatively little. The outer sea pier, according to the plan proposed by the Engineers, will enclose a large extent of shore as well as the Bay of Quick, and when carried out to the full extent, will be upwards of 3,000 feet in length. Within this area there will be space for two harbours, each 1,000 feet in length, 15 feet deep at low water, or 25 feet at high water, with entrances 100 feet wide. There will also be ample room for the construction of graving docks, for the storing of timber, and for the erection of sheds. Connecting the two harbours is shown, in dotted lines, the position for a lock 350 feet in length, by which one of the harbours can be converted into a wet dock, with a depth of 25 feet, when required; and at the west end is shown the site for a graving dock, such a work being also in contemplation. It is only intended, however, in the meantime to execute about one-half of the sea pier, and to form one harbour or tidal dock, the Albert Harbour, leaving the prosecution of the other works till the growing trade demands further accommodation. This from the present rapid increase of shipping will be at no distant period.

The depth of water along the line on which a cofferdam must have been constructed, had such been contemplated, is in many places nearly 30 feet at high water; and taking into account the length, and that it must have been of strength sufficient to resist the storms of winter, it could hardly have cost less than £50,000. Besides the great cost of a cofferdam, there was another difficulty, as, owing to the line of the proposed new pier being close to the edge of the deep-water channel, it would have been necessary to project the cofferdam so far into the channel, as to have formed a serious interruption to the traffic. In consequence of these difficulties, and from considerations of economy, it had been the intention of the Trustees to use timber for the outer piers of the harbour, and the Engineers were instructed to make their plans accordingly. It was the opinion, however, of the Author and his partner, that in a situation where the sea worm is very destructive, the work ought not to be constructed of such a perishable material, and that it was quite possible to build a solid structure, so as to avoid the difficulties referred to, in an economical manner. In order to effect this, they proposed to construct the outer pier and quays forming the seaward side of the dock, without cofferdams, so that the pier might itself serve as a cofferdam for the interior operations in the harbour which would afterwards be required. This seaward pier is 60 feet wide at the top, having quays on both sides.

The mode in which the work was designed was, to form the walls under low water of a combination of cast-iron guide-piles in the front, with a continuous stone facing slid down over and enclosing these, and of concrete backing deposited in a soft state, all of which could be easily accomplished from above the water line. Timber bearing-piles were to be used in the body of the walls where required, and the upper part of the walls from the low-water line was to be carried up of masonry in the usual manner. (Plate 9, Figs. 2 to 7.)

This plan was felt to be so novel, particularly with regard to the application of the concrete, that though the Trustees as a body had the greatest confidence in the Engineers, they considered it to be their duty before proceeding with the work, to fortify themselves by having the opinion of another Engineer. Accordingly, Mr. Thomas Page (M. Inst. C.E.) was consulted, who fully satisfied them as to the efficiency of hydraulic concrete applied in the manner proposed, and otherwise confirmed the soundness of the principles upon which the works were designed. At his suggestion, granite from the Ross of Mull was substituted for freestone, for the stone facing under the low-water line, as it could be obtained in large blocks at a moderate price; he also recommended that the timber piling should be dispensed with, but the nature of the bottom has hitherto not allowed this to be carried out to any great extent.

The first operation in the construction, when the water is not sufficiently deep, is to dredge out two parallel trenches to 17 feet below low water, for the foundations of the walls. A staging of timber piles is afterwards erected in the line of the pier over the whole breadth, for carrying the tramways, travelling cranes, and piling engines. Cast-iron guide piles are then driven from the staging, with great precision, 7 feet apart in the line of the face of each quay-wall. These piles are driven till their heads are near the low-water line, and they form guides for putting down the stone facing. They are connected at the top transversely by wrought-iron tie-rods stretching through the pier, cottered into sockets and binding the heads together. At first it was thought that there would be some difficulty in driving the iron guide-piles with the required exactitude, but this was overcome by pile engines of peculiar construction, devised by Mr. William York, one of the contractors. (Plate 9, Figs. 8 and 9.) These travel on the rails of the scaffolding, and are furnished with long arms projecting downwards, strongly stayed by diagonals, and forming a trough, into which the pile is placed, and from which it is driven by the pile engine in the manner of an arrow from a cross-bow, being obliged to go down perfectly straight.

The ground is very unequal, the hard substratum, or red 'till,' being in some places 20 feet below the bottom of the wall, the upper strata being mud and soft sand. In such cases timber piling, driven to the same level as the iron piles, is used to form a platform for sustaining the part of the wall above low water; but where the ground is firm this is not required. When the proper depth has been dredged out and the piling driven, a bed of hydraulic concrete 3 feet thick, and 20 feet wide, is deposited in the trenches, to form a base for the wall to spring from, and to give a large bearing surface. Into the grooves formed by the flanges of the iron piles, large granite slabs, from 18 inches to 2 feet thick are slipped, the bottom one resting upon the concrete base, and on a projecting web cast on the piles: not more than three stones fill each compartment between the piles 16 feet in height and 7 feet in width. These stones slip into their places with the greatest ease, and form the face of the wall under water. Behind this facing hydraulic concrete is lowered under the water in large boxes having moveable bottoms, and is discharged in mass to form the body of the wall. To confine this at the back before it has set, loose rubble stones are deposited and carried up simultaneously with it. The hearting of the pier, consisting of hard 'till,' stones, and gravel, is deposited afterwards, and the whole carried up to the level of low water.

The entire mass, piles and stone facing, concrete backing and hearting, is allowed to consolidate for a sufficient time; after which the heads of the iron piles and the granite facing blocks are capped at the level of low water by a granite blocking or string course, and the upper portion of the walls is carried up in freestone ashlar, and rubble. The remainder of the hearting between the walls is then filled in, and the whole is finished with a granite coping and causeway. The walls are 33 feet in height from the foundations, 11½ feet thick at the concrete base, and they diminish to 5 feet thick at the top.

Particular care is taken with regard to the hydraulic lime. It is burnt at the quarries, but is brought from thence in the 'shell' by the railway in covered waggons, so as to preserve it from wet. It is ground at the harbour works, for which purpose, and for mixing the mortar, there have been erected four vertical double-roller mills and two sieves, driven by an engine of 20 H.P.

In the part of the pier which has been already executed, the stone facing under low water being made to slip into the groove formed by the flanges of the iron piles, the outer flange is left exposed to the action of the salt water, which no doubt will in the course of time exert an injurious effect upon the iron. (Plate 9, Figs. 4 and 7.) To remedy this, it is intended in the remainder of the work to reverse this plan, and to make the grooves in the stone facing, into which the outer iron piling will fit. (Plate 9, Figs. 2 and 5.) The stone blocks will therefore overlap the iron piles, and form a continuous stone facing, so that no part of the iron will be exposed to the action of the salt water. The grooves will be filled from the top with cement, which will enclose the iron flange, and effectually preserve it.

When the whole extent of the seaward pier is completed, the interior operations for the harbour will be proceeded with. This pier will serve as the principal cofferdam, and the entrance will be closed by a short cofferdam about 100 feet in length, and then the water will be pumped out from the enclosed space; after which the excavation, and the construction of the interior walls surrounding the harbour will be commenced. It is not intended to describe these operations, as they do not possess much novelty.

The cost of the outer or sea piers, 1,200 feet in length and 60 feet wide, constructed in the manner described, will be £63,000.[1]

The concrete employed is formed of Arden hydraulic lime, iron-mine dust, sand, gravel, and stone chips,—the lime and the mine dust being well ground, under edge stone mills, before being mixed with the other materials. The proportions are by measure:—one part of ground lime, half a part of mine dust, one part of sand, and three parts of gravel and stone chips. Immediately after being mixed, and when brought to a proper consistency with water, it is conveyed to where it is to be used, is let down under water in the discharging boxes, and in a short time sets very hard. The boxes used are either of iron or of wood, and contain one cubic yard each. Those of iron are found to be preferable, as the buoyancy of the wooden ones renders them somewhat unmanageable in a tideway, after their contents have been discharged.

The works of the Albert Harbour are being executed under the immediate superintendence of Mr. John Thomson, C.E., as resident Engineer, the contractors being Messrs. W. and J. York.

This mode of constructing walls in deep water without cofferdams has proved very successful, and a sea-pier of great solidity and durability has been formed at a comparatively moderate cost.

In constructing quay-walls on the foregoing principles, different modes of forming the stone casing may be employed; and particu-

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* It has recently been decided to increase the area of the Albert Harbour, by building the south quay 90 feet further back than is shown on the plan (Plate 9, Fig. 1), the necessary land having been acquired. In connection with the harbour works, and to dispose of the materials from the excavations, amounting to nearly half a million cubic yards, it is intended to form an esplanade, or embankment, 100 feet wide, along the shore of Fort Matilda. This will be faced on the seaward side by a substantial wall, 6,000 feet in length, with landing-stairs opposite the principal streets, and the wall will be surmounted by an iron balustrade. The cost of the several works will be—

Albert Harbour and Albert Quay	£150,000
Sea-wall and roadway of esplanade	20,000
Land	50,000
Cranes, rails, &c.	10,000
Total . .	£230,000

larly where stone of a softer nature than granite, such as limestone or freestone, is used, a still more efficient outer casing may be obtained. (Plate 9, Fig. 6.) In it, blocks of stone, having orifices or holes cut in them, are strung or put down over the iron piles, so as completely to enclose them. These blocks have also grooves or projections on their sides, in which are slid down intermediate slabs or blocks of stone, having corresponding grooves or projections. A continuous facing of stone, having all the stones locked into each other, is thus formed, and the iron piling is effectually enclosed. It was on this principle that the facing under low water was intended to have been formed at Greenock, previous to its having been suggested to employ granite instead of freestone. Still further to protect the iron from the action of the salt water, the holes round the piles would be filled up from above with cement well-rammed down, so as to fill up all the joints, and to unite the stone and iron together. This plan admits of the iron piles being kept further apart than when single blocks connect the piles. Concrete backing may then be filled in, and the structure be completed as previously described. Temporary sheet piling or boarding, instead of loose stone, may be employed to keep the concrete in its place until it has set. In many cases, blocks of béton, which can be easily moulded into the shapes required, may be advantageously substituted for stone in the facing, as it has been proved by experience that, when properly made, they possess the requisite strength and durability.

The range of different purposes to which this system of founding marine structures is applicable is very extensive, and works such as the formation, re-facing, or re-construction of quay-walls; the formation of docks or tidal basins on sites covered by the sea; embankment walls along the shores of seas or rivers; the foundations of lighthouses, beacons, or forts which may require to be made in the sea; the construction of breakwaters enclosing harbours of refuge; may be effected with a speed, facility, and economy not hitherto attainable.

The applicability of this system to the construction of breakwaters, and the necessity for some mode by which the cost of these works may be lessened, seem to the Author so important, as to deserve further remarks.

APPLICATION TO THE CONSTRUCTION OF BREAKWATERS AND HARBOURS OF REFUGE.

Although various Royal Commissions and Parliamentary Committees have elicited much valuable information on this subject, the main object of diminishing the enormous cost of these works, and of providing a durable and substantial, and at the same time economical, barrier to the force of the sea, is as yet a desideratum.

So important, indeed, has this become, that in 1860 a Select Committee of the House of Lords was appointed to inquire, how far it might be practicable to adopt some plan, for the construction of breakwaters and harbours of refuge, less costly than the system of solid masonry then in use. Various plans were discussed, and amongst them floating breakwaters; but the investigation failed to establish any effectual substitute for the present modes of construction.

The plans about to be described will, in the Author's opinion, have a material effect in filling up this want. Before proceeding, however, it will be necessary to refer, briefly, to the principal modes of construction hitherto adopted, and to consider the peculiar phenomena by which such structures are affected.

The most common mode of forming breakwaters is the 'pierre perdue,' or 'long slope' system. This is simply the deposit in the sea of a vast amount of loose rubble stone, rising to about the level of high water, allowing it to take its own level, and to be acted upon by the sea, until its section assumes the permanent form which this action gives it. The seaward side obeys the laws of ordinary sea beaches, and forms itself into a long sloping shore, involving the employment of an enormous amount of material before the mound reaches the height to give the required protection. Such a system is only applicable where stone is abundant, and can consequently be deposited at a cheap rate. Of this system, the Plymouth, Cherbourg, and Holyhead breakwaters may be taken as examples. (Plate 10, Figs. 1 and 2.)

In situations where stone is not abundant, the opposite principle, called the 'vertical system,' is adopted. In this mode the walls are built upright from the bottom; and as all the material below low water is put in place by diving apparatus, and is of an expensive nature, the cost of a work executed in this way is very great. The Dover Breakwater, in course of construction, is the most prominent example. It is built up solid from the bottom of the sea, the exterior facing being of ashlar granite blocks rebated, or checked into each other, and the hearting of rectangular blocks of concrete, built in the same way as ashlar masonry up to the level of high water, above which it is filled in with liquid concrete. (Plate 10, Fig. 7.)

Besides these systems, which may be taken as the extremes, an intermediate form of section, combining both to a certain extent, is adopted. It consists in carrying up a rubble mound to within a certain depth below low water, and upon this, building the remainder of a vertical construction. The Alderney Breakwater may be taken as representing this system to a partial extent. (Plate 10, Fig. 10.)

It has been a subject of discussion, as to whether the 'long slope,' or the 'vertical wall' was the better section for breakwaters, and as to the relative force of the sea exerted upon them. The observations which have been made on waves may be said to have settled this point in favour of vertical walls, as it has been clearly shown that waves in deep water are chiefly oscillatory in their character, the fluid having little progressive motion in itself, and consequently exerting but little force on objects opposed to it; but in shallow water, waves assume an entirely different character, as they acquire a progressive motion, becoming waves of translation, in which the fluid is carried bodily forward in a horizontal direction, and in consequence it strikes any body opposed to it with great percussive force. Vertical walls, therefore, which rise from the deep water, being only subject to the oscillatory movement of the waves, are least exposed to the destructive effects of storms. The evidence taken before the Royal Commission in 1859 seemed to be conclusive on this point, and the opinions of the Commissioners, as developed in their Report, may be considered to have set this subject at rest. But whatever difference of opinion there may still be upon this matter, there can be no question as to the vast saving of material by vertical walls, and of the great economy which would result, provided a simple and easy mode of construction could be adopted. The vertical system has, besides, the great advantage of being applicable in many cases as quays for vessels lying alongside to load and discharge, which may be turned to valuable account both for commercial purposes, and, in times of war, for the rapid shipment, or debarkation of troops, stores, and other material.

The experience, however, derived from the formation of the great breakwaters on the 'pierre perdue' or 'long slope' principle, such as Plymouth, has been very valuable. The examination of the sections which the materials assume, shows that the great disturbing action of the sea, or conversion of the waves of oscillation into those of translation, does not extend to any considerable depth; as it is found that the long sloping beach terminates generally at from 12 feet to 15 feet below low water, after which the inclination becomes much steeper, the materials assuming nearly the form due merely to the natural angle of repose, as if unacted upon by any force except that of gravity. The inclination on the seaward side within the tidal range, and to the depth of 12 feet or 15 feet below low water, is generally five or six horizontal to one vertical, but below that depth it is only from one to one and a quarter horizontal to one vertical. It is the long slope which these breakwaters assume to a certain depth, that causes the enormous absorption of material; but it appears that a mound of rubble may be deposited to within a certain distance of low water which will not have this long slope, and consequently will only require a comparatively small quantity of material. The consideration of these facts shows, that in the generality of cases, the vertical and 'pierre perdue' systems may be combined with advantage and economy, by first depositing a rubble mound to about 15 feet below low water, and from that point carrying up the remainder of the breakwater by vertical walls.

A great improvement in the facility of constructing these breakwaters, when such an immense quantity of material has to be deposited, was the introduction, by the late Mr. Rendel, of timber staging carried on piles in advance of the work, and sustaining lines of rails, by which the material can be brought down and be deposited in the sea with a rapidity before unattainable. The consumption of timber is, no doubt, very great, as much has to be left imbedded in the work, and there is considerable destruction besides; but this is amply compensated by other advantages. By this system, an average of about a million tons of stone a year have been deposited at Holyhead, and a similar plan is pursued at Portland.

Massive staging is also employed at the vertical breakwater at Dover, for facilitating the building operations. Indeed, staging may now be considered essential in the generality of cases for the economical construction of such works.

The breakwaters of the French Engineers are generally formed 'à pierre perdue,' but upon a different method from that pursued in this country. Thus, at the Plymouth Breakwater, only large blocks of rubble stone were deposited, the small being thrown aside, and at Holyhead and Portland, the large and the small rubble were deposited promiscuously; while the French Engineers usually employ the small rubble for the core, and reserve the larger blocks for the outer coating. Furthermore, they protect the seaward side by blocks of béton, thrown in to take their own position, and of such a size, (generally from 20 tons to 30 tons), as effectually to resist displacement by the utmost force of the waves. These blocks assume a slope as steep as one to one under the water line, so that the mass of material in a breakwater thus constructed, is considerably less than where smaller materials are employed for the seaward face. The moles of La Joliette and Napoleon which enclose the harbour of Marseilles, are excellent examples of this mode of construction. (Plate 10, Fig. 3.)

Having thus glanced at the general principles which affect breakwaters, and described the modes of construction usually adopted, the conclusion to be arrived at appears to be, that the vertical system is that which best resists, or rather averts, the destructive action of the sea, and requires the smallest amount of material. However, both systems, the 'long slope,' and the 'vertical,' as at present carried out, are very expensive, the former from the quantity of material which is required, the latter from the costliness of the material and the mode of construction. The one system may be characterized as involving the maximum in quantity, and the minimum in cost of material; the other, on the contrary, the minimum in quantity and the maximum in cost of material. The object sought to be attained by the system about to be described, is to effect a minimum, as far as possible, both in the quantity and in the cost of the material.

According to circumstances, breakwaters on this system would be constructed either wholly vertical, extending from the bottom, or partially vertical springing from a rubble mound. For the sake of comparison, the mode proposed by the Author (Plate 9, Figs. 10, 11, and 12,) is designed to suit the conditions usually prevailing; say a range of tide of 15 feet, and a depth at low water of 6 fathoms, being about the same as at the Plymouth Breakwater, and as at Hartlepool, Filey Bay, and the entrance of the Tyne, where the most important harbours of refuge have been recommended by the Royal Commissioners. The section (Plate 10, Fig. 6,) represents a breakwater with a parapet, but this is not indispensable to the main object of a breakwater, and is only required in certain cases, as where the inner side is to be used for commercial purposes. Where the parapet can be dispensed with, the top of the breakwater may be capped by large blocks of béton, or stone, of such a weight as not to be displaced by the heaviest seas. (Plate 10, Fig. 5.)

The principal feature of the new plan is a framework of iron, formed of piles, or standards, and ties, which serves as the staging for all the constructive operations, and afterwards becomes an essential portion of the structure, by binding together a strong casing of stone or other sufficiently durable material, which encloses and forms the facing of the breakwater, allowing the interior to be filled up with loose rubble, or other cheap materials, which may be cemented into a solid mass by means of liquid béton or concrete. It will be preferable for breakwaters to make the standards of wrought-iron, and in the generality of cases it will not be necessary to drive them into the ground, but simply to set them in place.

The mode of proceeding is to erect the iron staging in advance of the work, which may be done, either by driving, screwing, or guiding the piles, or standards, from a machine placed on the platform, and travelling along as it progresses. This machine will have long guides firmly stayed and set accurately in position, into which the iron piles will be placed, and then driven in a similar manner to that pursued at Greenock. When two piles are erected in place, they are connected transversely by iron ties, and by the temporary platform at the top for bearing the rails, and the piling machine is then moved on to drive the next set, and so on. Following this operation come the wagons depositing the material to form the rubble mound, which collecting round the lower part of the standards, firmly fix them in their places, and give stability to the staging. When the mound has risen to the required height, say 18 feet below low water, the cranes from the staging above commence lowering the casing blocks for the facework. These are made to enclose the iron standards, and are formed so as to be arched or locked into each other, and thus to resist any pressure arising from the backing. They can be made to break bond, or to slide down without breaking bond, as may be considered desirable; but the former plan permits the standards to be kept at a greater distance apart, and the blocks to be of less dimensions, and at the same time, of greater strength.

Simultaneously with the building of the casing, the hearting of the work, rough rubble, or other suitable material, is to be deposited from the wagons on the staging, filling in from the centre, while backing of béton, or hydraulic concrete, will be lowered down in large boxes, and discharged behind the stone casing, consolidating and cementing together the rubble hearting, as it is filled in and falls down.

It will be observed, that the whole of the facing is rendered continuous; and by all the blocks being arched, or grooved into each other, it is impossible that any individual block can get out of place. This is a danger greatly to be feared in structures of this kind built in the ordinary way, as the action of the compression of the air in the joints of the masonry, by the pressure of the waves, and the after-expansion when the waves retire, is sometimes so great as to blow out the stones, thereby endangering the whole structure.

By this system the Author believes great solidity and strength may be obtained, as the whole structure is bound firmly together by the iron framework; while the manner in which the stones of the facing are locked into each other, and in which the concrete will penetrate and solidify in a short time the whole mass, will realize as nearly as possible the idea, which should be the object of attainment in such structures, of a monolith, or solid rock in the bed of the ocean.

The cost of such a structure, under ordinary circumstances, and of dimensions suitable for Hartlepool, Filey Bay, or the entrance of the Tyne, may be taken at £190 per lineal yard without a parapet, and at £200 per lineal yard including a parapet wall, according to the following estimate, in which the same prices are taken as were assumed by Mr. John Murray (M. Inst. C.E.) in a previous discussion at the Institution.[1]

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xviii., p. 104.

Estimate of the quantity of material in a bay of 15 feet of a breakwater, with 36 feet depth at low water and 15 feet range of tide.

			£.	s.	d.
150	cubic yards rubble in outer coating of mound	at 4s. 6d.	33	15	0
550	cubic yards rubble in body of mound (deducting one-fifth for interstices)	at 3s. 6d.	96	5	0
2,970	cubic feet béton blocks in facing under low water	at 1s. 8d.	247	10	0
2,250	cubic feet ashlar facing above low water	at 1s. 6d.	168	15	0
547	cubic yards rubble hearting (deducting one-fifth for interstices)	at 3s. 6d.	95	14	6
70	cubic yards concrete backing	at 10s.	35	0	0
33	square yards causeway	at 10s.	16	10	0
119	cwt. wrought-iron standards (100 lbs. per foot)	at 30s.	178	10	0
22	cwt. wrought-iron transverse ties (3 inches diameter)	at 30s.	33	0	0
5	cwt. wrought-iron longitudinal ties	at 30s.	7	10	0
	Parapet.				
907	cubic feet ashlar facing	at 1s. 6d.	68	0	6
9	square yards causeway	at 10s.	4	10	0
30	cubic yards concrete	at 10s.	15	0	0
			£1,000	0	0

£1,000 ÷ 5 = £200, the cost per lineal yard of breakwater with parapet wall; and making deduction for parapet and addition for capping blocks, £190 per lineal yard would be the cost without parapet wall.

The blocks forming the casing under water may be either of stone or of béton. When the former cannot be conveniently procured, the latter may be used with advantage, particularly as it can be so easily moulded into the required shapes, and almost of any size. The power of such blocks to resist the action of the sea for an indefinite period is now fully confirmed. These may at least be generally adopted for the inner walls of breakwaters. Indeed concrete blocks, built in the ordinary way, have been already used by Messrs. Walker and Burges at Alderney for the inner facing.

The great economy of this system of constructing breakwaters would arise from the smallness in quantity and the cheapness of the bulk of the material. The quantity of material in this breakwater compared with that in the Plymouth Breakwater on the long slope principle, in the same depth of water will be about as one to four, and the disparity of cost is not less striking, the Plymouth Breakwater having cost nearly £900 per lineal yard.

In comparing with any other mode of construction, the iron framework may be allowed to go for nothing, as staging of some kind must be used for the speedy and economical construction of any kind of breakwater. This framework of iron standards will not cost more than timber staging, and, indeed, far less than in cases where an immense quantity of staging requires to be used for the deposit of the enormous mass of material of long slope breakwaters, such as at Holyhead; while it will be far more secure, in consequence of its inherent strength, the heavy nature of the material, and the small surface presented to the action of the waves. The buoyancy of timber staging is an element which causes its own destruction, as is exemplified at Holyhead, where it is admitted that for every piece of timber another piece is required to make up for the loss.

Another important advantage is the great speed with which it may be constructed, from the mass of the material being of a nature easily deposited, and from the facility with which operations may be carried on upon a long stretch of the work at one time. In situations where the materials for the construction of ordinary breakwaters cannot be obtained, the advantages of this system would be still more striking. Dover may be taken as an example, there being no stone in the neighbourhood suitable for depositing 'à pierre perdue,' or building vertically in the usual modes of construction. By the system proposed the harder chalk from the cliffs, and shingle, could be used for the hearting, as in a structure so firmly bound together these materials concreted with béton would serve the purpose quite as well as any other. In forming the rubble mound, the example of the French Engineers might be followed with advantage, by forming the core of smaller and inferior materials, and for this the chalk and shingle would be quite suitable. This would be protected by a thick layer of rubble, and on the seaward side by a layer of concrete blocks, of such a size as would not be disturbed by the sea. The vertical superstructure would be constructed of chalk, or sandstone rubble, concreted by béton for the hearting. A breakwater upon this construction (Plate 10, Fig. 8,) the Author estimates could be built at Dover for £290 per lineal yard. The present breakwater for the same depth of 45 feet at low water is contracted for at £1,245 per lineal yard, so that there would be the enormous saving of upwards of one million and a half sterling per mile. The difference in the cost of construction, vast as it is by this system, is not the whole saving, as the time occupied is an important element, affecting the final cost of such a work, the interest on the outlay being lost until the harbour becomes available. There can be no doubt of the solidity and durability of the Dover Breakwater, but considering its enormous cost, and the distance into the future before its completion will render it available for commercial or for war purposes, the wisdom of prosecuting it upon the present mode of construction may be well called in question. Upon the construction proposed, the breakwater could be completed and be available as a Harbour of Refuge for the naval and commercial fleets of the country in less than five years, at a cost of little over £1,000,000.

Breakwaters and piers have been frequently made of timber framing and casing, confining a mass of rubble. Extensive piers on this principle are in existence at Boulogne, Calais, Dunkirk, and other ports; but it is evident that such a system, from the timber being exposed and the consequent want of durability, and from their liability to sudden destruction when once the casing gives way, must prove very expensive in the end. This system has been revived, though upon more scientific principles, by Mr. Abernethy (M. Inst. C.E.) and Mr. Michael Scott (M. Inst. C.E.).[1] In these plans a structure, composed of a casing of timber, is formed of timber frames, standards, or piles and planking, and this casing is afterwards filled with rubble. But as the casing cannot be expected to possess much durability, it is proposed subsequently to enclose this structure by solid walls of masonry or composite blocks, for which the first structure will afford a convenient and substantial platform, for bearing the rails and cranes necessary for executing this part of the work. There are two distinct operations necessary, therefore, to complete the work upon this mode in a permanent manner; first, the formation of the inner structure with its timber casing; and, second, the formation of the outer structure, for the purpose of making a casing of a durable character. The economy of making breakwaters of a durable construction on these modes has not been fully made out, chiefly arising from the great quantity of timber required, and the necessity of employing two distinct casings, one of which must be superfluous.

The system which the Author has proposed, will he thinks secure all the objects which appear to have been aimed at by these plans, but with greater simplicity and economy.

It is not essential that the standards employed in the system proposed by the Author, should be of iron, as they may be of timber, but enclosed, as has been already described in the case of iron standards, in a casing of blocks of stone or of béton. The Author, however, would not recommend this, except for small piers, or breakwaters where great economy is necessary.

Application to the Foundations of Marine Fortifications.

The general application of steam to ships of war, the improvements in artillery, by which the range and weight of projectiles have been vastly extended, and the system of coating ships with defensive armour, have entirely changed the relations of works of defence on shore to those of offence from sea, and rendered the supervision of the system of fortifications which defend the naval arsenals and seaports, a question of vital moment. The present defences have been found to be quite inadequate to cope with the new forces which can be brought against them, and in particular, a necessity has been felt for the construction of advanced works, which shall keep the enemy without the range of bombarding the places they are intended to protect, or at least subject them to severe punishment while attempting it. In some cases, these can only be constructed in the sea, and in others, this is the most effective situation for them. It is in this way that Cronstadt is protected, and it forms an important part of the general scheme of the new works for the defences of Plymouth and Portsmouth. There are many considerations that will render sea-forts of great value, which need not be entered upon in this place. Suffice it to say, that it is probable the use of such advanced works will be much extended, and many situations could be pointed out where forts could be more advantageously placed in the sea than on the land, for the protection of seaport towns. The difficulty, however, in the way of executing such works, is the expense and delay in constructing the foundations. The Author is of opinion, that the principles already described for works of a different nature, would admit in this case also of successful application for the works under low-water level. The casing might be of granite, or the greater part of large concrete blocks, capped near the low-water line, where exposed to shot, by a massive blocking course of granite. The manner in which the filling in of concrete in the interior would set in a solid mass, and in which the whole structure would be bound together by the iron standards and tie-rods, would, the Author apprehends, form as efficient a foundation for the purpose as could well be devised, while the rapidity and economy with which such a work could be put down, would certainly be advantageous.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xviii., p. 72; vol. xix., p. 644; and vol. xxi., p. 322.

In developing the foregoing system for constructing the submarine works of breakwaters, piers, quay walls, lighthouses, fortifications, and other similar structures. it must not be understood that it is advocated as being applicable in all cases, as the mode of construction of any engineering work must be determined greatly by local circumstances. But the Author considers that it will admit of general application, and that the following advantages may be fairly claimed for it:—

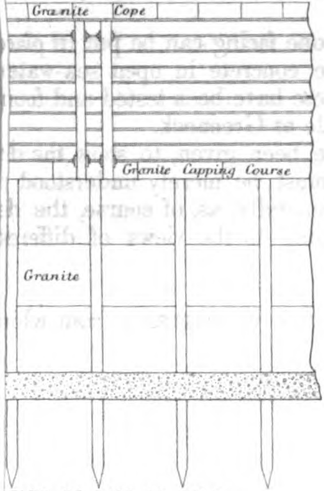
Great economy, combined with strength and durability;
Facility and rapidity of execution;
Adaptability to situations where the present modes are inapplicable.

It is to be expected that there will be considerable doubt and diversity of opinion regarding the various operations involved; such as the accuracy with which the guide-piles or standards can be driven, the facility with which the stone facing can be put in place, or the depositing and setting of the concrete in open sea-water; but it must be recollected that all these have been tested and found successful in works upon a large scale at Greenock.

The various examples which have been given, to show the different applications of this system, must be merely understood as intended to illustrate the subject generally, as, of course, the details will admit of variation, according to the views of different Engineers.

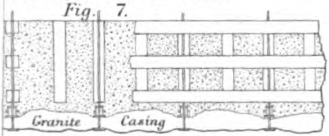
The Paper is illustrated by a series of Diagrams, from which Plates 9 and 10 have been compiled.

Fig. 4.


Granite
Cope
Granite Capping Course
Granite

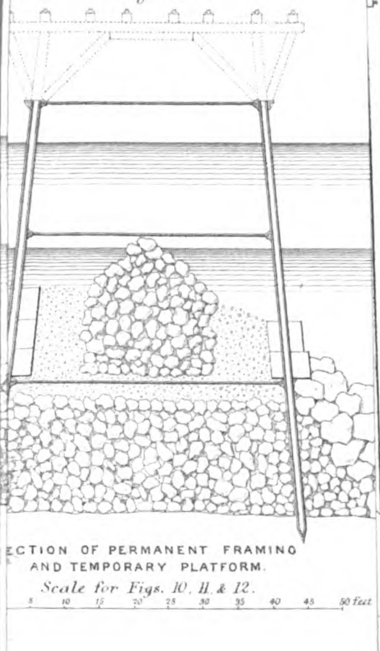
ATION OF PART OF PIER.

Fig. 7.


Granite
Casing

PART OF PIER AT LOW WATER.

Fig. 12.

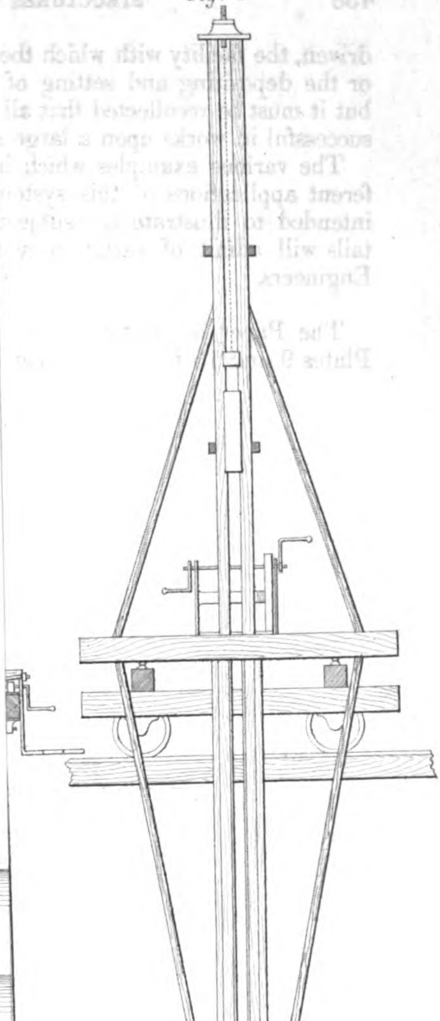


ECTION OF PERMANENT FRAMING AND TEMPORARY PLATFORM.

Scale for Figs. 10, 11 & 12.

5
10
15
20
25
30
35
40
45
50 Feet
10 feet

Fig. 9.



KELL BRO^S LITH^RS CASTLE S^T HOLBORN

Mr. MILLER stated, in reply to questions, that the contract for the pier at Greenock, complete in every respect, 1,200 feet in length and 60 feet in width, had been taken for a sum of £63,000, being at the average rate of £157. 10s. per lineal yard. As yet only about 300 feet in length of the pier had been completed. No difficulty whatever had been found in getting the concrete to set, and to become thoroughly consolidated, even under water 15 feet or 20 feet deep at low water; and although occasionally there were strong northerly winds and heavy seas in that part of the Clyde, yet the concrete was as solid as rock, and so hard that iron bars would not enter it. Much depended, of course, upon the quality of the materials used in forming the concrete, and upon the mode of preparation. The Paper would be found to contain detailed information on this branch of the subject.

Mr. JOSEPH MITCHELL remarked, that the water at Greenock was generally very quiet. From his experience he apprehended that, with rough water, there would be difficulty in getting the concrete to set firm. In some cases he had found that the lime and the sand were washed out by the water, and only the large gravel remained. That appeared to him as likely to arise in depositing concrete in boxes, in the way which had been described.

Mr. GREGORY, V.P., observed, that there could be no doubt as to the structural advantages of concrete, if it was allowed to set, and if the materials of which it was composed were not washed away. But concrete generally required a casing to protect it: and while he gave full credit to the Author for the ingenuity of the construction of the casing, which carried out the same idea as that which had been adopted in the piers of Westminster Bridge, he feared that, where exposed to a heavy sea, it would be found that there was not sufficient bond between the casing and the body of the work. It was well known that water would often penetrate through the joints of masonry, and whatever might be the precision of the work, he apprehended there would be a risk of the water finding its way behind the casing, and along the line of the bolts, which appeared to be the only means by which the casing was held to the body of the work. He thought that when such a structure was exposed to a heavy sea, damage might from this cause occur to the casing, and incidentally to the whole mass. When using concrete as the hearting for a wall, he had frequently adopted counterforts and bond courses running back from the casing walls, so as to unite them with the mass of the work. It was possible that while in rivers, or estuaries, where there was no great run of sea, the system described might, under certain circumstances, be adopted with advantage, it was necessary to pause before using it for walls which required to be well bonded, when they might be exposed to the action of the sea in harbours or breakwaters.

Mr. J. F. **Bateman** thought the Author did not mean it to be supposed that the outer casing was in itself completely water-tight, so as to form a close coffer-dam. He had no doubt that concrete, when properly made, would set as hard as the old red sandstone conglomerate; but there was the risk of the water sucking out the lime before it had become set, and leaving only the gravel behind. In the structure under discussion, there was certainly a want of bond, as had been already pointed out; and he feared that, in a heavy sea, the whole of the veneer-like facing would be stripped off, leaving the rubble backing and the concrete hearting entirely exposed. That, however, would not be of much consequence, if sufficient time had elapsed to enable the hearting to become consolidated, and if the primary difficulty, of preventing the water from sucking out the lime and depriving the concrete of its cementing property, were overcome. If the concrete was of good quality, then the plan described would, no doubt, if successful, ensure a very economical kind of work, and in that view it was deserving of consideration. At the same time he thought more experience was required to enable its intrinsic merits to be fairly judged of. It would be necessary, in order to give every chance of success, that the concrete should be composed of excellent hydraulic lime, and sharp stones, with little or no sand, so as to possess no particles which could easily be removed, and that the whole of the work should be well bonded together. Although Portland cement, undoubtedly, made the best concrete, where rapid setting was required, a good concrete could be obtained without the use of cement. For instance, he had frequently employed the Halkin Mountain lime, and the concrete in which it was used set as hard as rock. The character of the concrete depended upon the quality of the lime, and the proper apportionment of the lime to the broken stone or shingle. When lime was used the concrete would not set so quickly as with Portland cement.

Mr. F. J. **Bramwell** said, it appeared to be assumed that cast-iron was an improper material to be used in the sea. He should like to know, whether that had been satisfactorily tested in English waters, and also whether the applicability of that material did not depend, very much, upon the quality of the cast-iron; in other words, whether different results had been obtained from using grey or white iron.

Mr. **Beardmore** fully agreed with the concluding observation of the Paper, that everything must have its own special application. With regard to the adaptability of this form of construction to breakwaters, he remarked that the term itself implied a structure requiring such prodigious strength, that it was necessary carefully to consider the circumstances under which that form of construction was to be adopted. He had occasion to inspect the works at the Albert Harbour somewhat critically, and he thought that, regard being had to the local conditions, the plan was well chosen. In the Clyde at Greenock there was but little sea exposure, a heavy sea being in fact very rare. The worst evil that had to be contended with was a rather strong current; but when the first piece of work was finished, a cover was afforded against the current, as far as any washing effect was concerned. The foundation of the pier, generally speaking, was in the very strong 'till' usual in that part of Scotland, and was as good a foundation as could be desired; it was situated also advantageously for the excavation of a trench suitable for the reception of the basement bed of concrete. From his examination of the process of manufacture, he considered that both the hydraulic lime and the manufactured concrete were very good. The plan he had found to succeed best in the manufacture of concrete was, first to make a mortar of lime and sand, and then to mix and incorporate this mortar with the coarser material. With ordinary Thames ballast, for instance, a far superior concrete was made, by first sifting out the sand and blending it into mortar, and afterwards mixing with the remaining coarse material, than by making the concrete at once, by incorporation of the original gravel with the same proportion of lime. The former operation greatly improved the concrete, and economized the use of lime, or cement, especially if the ballast and sand were washed before they were used. He had examined the concrete at Greenock at dead-low water, where the surface of lime was being washed by the tide, and it appeared to be perfectly hard and sound. Even with an iron bar, he could not detect anything like softness; in fact, in that situation he doubted whether there would be any wash at all, so as to affect good hydraulic concrete deposited in large masses. This part of the work was well below the level of dead-low water, where the water was comparatively quiescent, and was subject only to the motion within itself. The rise and fall of the tide in the Clyde was very small, and there was scarcely a variation of 2 feet in four or five hours. In some cases, the extent of tide created the necessity for a high vertical wall, so that great strain was thrown upon the work, as at Liverpool, where the difference between the neaps and springs was as much as the whole rise of the tide at Greenock.

If he might give his opinion fairly upon this work—which he presumed was the object of the discussions at the Institution—he certainly looked with suspicion on the want of bond. On this point he would strongly advise the Author to be cautious. In the construction of a work like Westminster Bridge, there were two faces tied together, and intimately connected by cross ties; in fact the piers formed a wall with two faces; but in the pier at Greenock there was a mass of material 40 feet in width that might settle between the two walls, and the power that would be exerted on the ties by a small settlement would be very great. Therefore, not only was the strength of the ties important, but also the strength of the grooved iron piles, as they became in fact girders for sustaining the weight of the materials forming the hearting, and for conveying the pressure to the thin facing stones. The solidity of the structure in reality depended on the cast-iron piles, which should be very strong, and on the wrought-iron ties, which should be more numerous than might be deemed strictly necessary by mere theoretical considerations. With regard to the deterioration of iron in sea-water, his own experience did not lead him to anticipate much danger. No doubt, wherever there was sulphuretted hydrogen in the water, there would be a tendency to the decomposition of iron; but such cases were rare, and it was more frequently found, that the iron was completely protected by incrustation, particularly when entirely under water. Iron exposed to the tidal wash, and alternately wet and dry, was under another condition, and where it was above half tides it would waste to some extent, unless it was well protected. The chief difficulty in this plan of construction was, that the work was not open to inspection as it progressed. In the old-fashioned system of laying course after course, either by a diver, or from a bell, perfect bond was attained, and everything was seen. There certainly was the apprehension, that the concrete might not set thoroughly solid; but he supposed that in this case the concrete was tried at different depths. It would, however, be necessary to make up for the want of seeing what was going on under water, by giving great extra breadth and strength to the structure.

He thought there was little chance of any settlement in the portion of the work he had seen. A length of between 300 feet and 400 feet was finished, and it looked good, sound work; if there had been any disposition to settle there would have been some signs of it then. It was a proper application of the plan for the situation, but he should hesitate to adopt it generally. It was to be hoped that there would be an improvement in the mode of carrying out similar large structures, as at present a great heap of spoil had to be run out, unless vertical walls could be adopted; but that must be regulated entirely by the situation, and by the judgment of the Engineer in charge of the works. If the proposed plan were generally followed, he would recommend a greater number of ties, so as to afford a substitute for bond; because the plan meant the abandonment of bond, in the old-fashioned sense of that term.

He had used, somewhat extensively, Kentish rag-stone, and also brickwork, as a veneer, with a backing of concrete, formed of ballast and Portland cement, in the proportion of about six to one.

He had recently occasion to pull down a wall, built in that manner, about nine years previously, but he found that the work was too strong to be broken up, so that he let the rough concrete remain as the lower part of the wall, and trimmed off a face, and then underpinned several feet in depth with brick piers, with concrete forced in behind. In regard to the use of concrete in large foundations, it ought never to be forgotten, that the heavier and larger the mass put in, the greater was its power of consolidation and chance of absolute and permanent setting into hard rock. When good hydraulic concrete was used, in large masses, the general mixture with, and surrounding of, water was a great aid to the soundness of the work.

Mr. F. W. Sheilds said, he had known a mass of concrete 9 feet square, when taken up, after having been deposited six or seven months, to be quite soft, although made with the best lime. It hardened, however, almost immediately on exposure to the air. He thought Portland cement was much preferable to Roman cement, and should be used wherever a first-rate concrete was required. He had found ordinary masons' chippings an excellent material for concrete, and superior to gravel alone. When they could be procured in sufficient quantity, and were mixed with gravel and with a due proportion of Portland cement, a very reliable material was obtained. He had put in the foundations of the tall water-towers at the Crystal Palace in that way with the best results. He quite agreed that the want of bond was a very doubtful feature in the walls constructed upon the plan described in the Paper.

Mr. Cockburn Curtis said, the principal thing to be regarded, with reference to the more extended application of the mode of structure advocated in the Paper, was the situation in which the works were to be placed, more particularly if proposed to be applied to harbours of refuge. The most important point in the construction of harbours of refuge was the 'lead' of sea, and, especially where concrete was concerned, the rise and fall of the tide. He thought it would be sufficient to say, that the works under consideration, and which were proposed as a model for others of a larger character, were situated in a place completely land-locked, and between 40 miles and 50 miles from Ailsa Craig, so that the 'lead' of the sea was inconsiderable, not exceeding 3½ miles. The rise and fall of spring tides was only 12 feet, and the difference between spring and neap tides only 8 feet. This showed, to those conversant with the subject, that this form of structure, looking to the want of bond and other particulars previously noticed, could not be applied in exposed situations, such, for instance, as at Alderney.

Mr. W. A. Brooks said, with regard to the form of breakwaters, the Author had expressed the opinion, that the vertical wall was the best, for resisting the destructive action of the sea, and that it took the least amount of materials. This opinion was entertained by many persons, and appeared to be based on the belief, that a deep-sea wave had only an oscillatory movement. He thought that was an erroneous supposition; because it was known that, in a gale of wind, there was a pressure of from 30lbs. to 40lbs. per square foot, blowing for hours in one direction, and therefore the waves must have a progressive motion. It was found, also, that when the wind shifted from one quarter of the compass to another, the sea went down directly. If there were only an oscillatory motion of the waves in deep seas, there would be no occasion for ships to lay to for fear of being 'pooped.'

The piers of the deep-water harbour at Kingstown were constructed with long slopes of 5 to 1, and the cost of the granite used there did not exceed eighteenpence per ton. Those acquainted with quarrying knew, that with a 'lead' of only 2 miles or 3 miles, any rock might be quarried and put into the sea at a shilling per ton. No doubt when the wall could be executed at that cost, breakwaters, or piers, with long slopes were the best, both as regarded strength and economy. Many millions of money might have been saved to the country, if the Engineers of the last twenty years had followed the excellent rules laid down by Smeaton, Telford, and Rennie. In the recent harbour works, it was proposed to build them with vertical walls; but there was no work, except the Admiralty pier at Dover, in which that principle was really adhered to. At Alderney the pier was a compound of the worst forms. The substructure aided the progressive motion of the waves, while the vertical wall gave them a back sweep, which must in time destroy the rubble foundation and carry away the stones. Nothing could save the superstructure, or vertical wall, but an immense addition to the foreshore, eventually making the Alderney Pier a long-slope work. It was stated that the stones on the rockwork slope were converted into boulders, rounded from being tossed up against the facework of the masonry by the action of the waves. That showed a bad system of construction. A great mistake had been committed, in treating certain small harbours in Ireland, as being formed of piers with long slopes, whereas they were not more than $2\frac{1}{2}$ to 1, or 3 to 1. If all had been 5 to 1 or 6 to 1, no objection could have been raised to long slopes. The late Sir W. Cubitt had stated, in one of his Reports, that he deemed Kingstown Harbour to be the best and cheapest work of the kind in the British dominions, in proportion to its size and extent. That opinion certainly did not favour the system of construction that was now adopted for public harbour works. He had heard with regret, that no refuge harbour works for the north-east coast of the kingdom would be assisted by the Government until the public harbours, now in course of construction, were finished. Hundreds of lives would, therefore, continue to be lost, before anything was done, in places where those works were so greatly needed.

Mr. J. JENNINGS thought, as the method of construction then under consideration appeared to be greatly dependent upon the iron ties, that the question of their durability was of the utmost importance, as well as the extent to which iron bond might be advantageously made use of in concrete work, and, whether in the form of hooping, or of rods. When he had cut into work where iron had been used in concrete, he had found the iron decayed to a considerable extent; but, at the same time, a hard metallic compound had been formed round the iron, which might lead to the supposition, that it would not decay throughout its whole thickness. With regard to the manufacture of concrete, recent experiments tended to show, that if made with a much smaller quantity of water than was usually employed and sufficiently punned, as hard and compact a substance as limestone would be formed in a short period. This, of course, was a point to be determined by experience. It was said that a labourer could only produce two or three yards of concrete on that principle in a day; but although such an amount of labour would cause an increase in the cost, yet this would be compensated for, by the better quality of the material. He had used Roman cement for concrete twenty years ago, and the result of his experience was, that concrete formed with that cement was very satisfactory and stood perfectly. The setting of the concrete was as perfect as could be desired, although the tide came over it within a quarter of an hour after it was deposited.

Mr. JOHN WRIGHT said, in reference to the use of concrete, in large masses, when deposited under water, that some years ago he had built a wall which was 5 feet or 6 feet under water at low tide. That wall had a facing of brickwork 18 inches thick, and the backing was entirely composed of Portland-cement concrete. The turn of the tide was exceedingly quick and strong, and it washed over the concrete shortly after it was laid. The concrete he referred to was made of eight parts of Thames ballast mixed with one part of Portland cement, and it was deposited in the water immediately after it was made. It was not mixed by machinery. Three or four years afterwards, when it was requisite to take down a considerable portion of that wall, he had an opportunity of testing the quality of the concrete. It was then found to be as hard as solid rock, so that the removal of the wall was a most difficult operation, and an enormous quantity of gunpowder was consumed in blasting it. Therefore he was sure that well-made concrete was a very suitable material for works of construction, whether under water or not. Where there was not a great depth of water, he had found it an excellent plan, as soon as a face could be established against the water, to force in the concrete at the back, and keep pushing the face on. In this way, the concrete at the back did not come in contact with the water, and the surrounding water was not even coloured. When the water was charged with silt, mud or dirt would be deposited upon the concrete, so that the next layer would have a tendency to slide upon it, and would not bind with the mass below, unless the surface was cleaned. As a further illustration of the efficiency of concrete in large masses, Mr. Wright referred to the sea-walls he had built at Brighton. Some parts of those walls were 70 feet in height, and had already stood between twenty and thirty years, without at present giving any indications that they would not endure many years longer. The composition of the concrete in that case was lime and sand, in the proportion of three to one, made into mortar in the usual way, and one barrow load of that mortar was mixed with a barrow load of beach shingle in the pug-mill, after which the concrete was immediately pressed into the cases. As the result of his own experience, he felt convinced that concrete was generally made too dry. He believed that it should be used when in a fluid state, so that every particle might settle perfectly and then set, and that the sooner it was deposited, after being made, the better would be the result.

The Paper opened a wide field for discussion, as to building under great depths of water. On this subject he should endeavour more fully to express his views upon another occasion.

Mr. J. Brunlees called attention to a design, made by him two years ago, at the request of Captain Vetch, R.E. (Assoc. Inst. C.E.), for a breakwater and pier at Point de Galle. It would be seen that that design was almost identical with the system of construction now under consideration.

Mr. Parkes had found great difficulty in ascertaining whether concrete, deposited under water, had properly set. Although it might appear hard, when tried with iron rods, yet, in some cases, if pieces were brought up out of the water, they were discovered to be soft and 'crumbly.' He did not mean it to be inferred that he had any doubt that concrete deposited under water might, in the majority of instances, turn out very well, for he had formed foundations in this way entirely to his satisfaction. But he did not think that, at present, the theoretical knowledge of the action of hydraulic limes and cements under water was perfect. It was known, practically, that certain limes and cements would set in water, but not under all circumstances. What were the conditions necessary to insure success did not seem to be fully known. In any particular case, therefore, involving new conditions, there was a possibility of some essential precaution being omitted, and after the concrete had been deposited, it would be uncertain whether it was good, or not. It therefore seemed to him, that more than ordinary care was required before such a system as that practised at Greenock could be generally adopted. That such precautions could be taken as would ensure success, he had not the least doubt: but these would differ in each particular case.

With regard to the section of the pier at Greenock, an objection had been raised, as to the want of bond between the granite face and the concrete. It was in his opinion a fault, that there should be two distinct walls instead of only one to support the superstructure, one for the face and another for the backing, but he did not think that the two could be bonded together—that a concrete backing could be bonded with a granite facing. The concrete would either swell or shrink, and in either case the virtue of the bond would obviously be destroyed. The most natural course to have adopted would have been, instead of making the face-work an integral part of the wall, and allowing the superstructure to bear partially upon it, to have made it a mere shell, so as to protect the surface, and to allow the whole superstructure to rest upon the concrete. If the concrete set well, it would be quite as good as second or third class masonry; if not good, then it ought not to be there at all. It was contrary to first principles, that the superstructure should rest upon two substances so different in their composition as perfectly dressed granite and concrete. The piers of the new Westminster Bridge had been cited as a precedent for this principle of construction; but in that case there was an entirely different feature introduced, as the whole interior of the superstructure of the pier rested upon bearing piles, the concrete merely filling in the spaces between the piles. He believed it was part of the original design to use bearing-piles at Greenock, but that this was afterwards abandoned, and although they were shown on one section (Plate 9, Fig. 3), he understood the work had been executed according to the design shown on the other section, so that the outer edges of the pier rested upon the casing, formed of granite slabs, and the interior upon the concrete. No doubt the Author would be able to explain, why he had adopted a facing of granite of, he believed, 2 feet thick, rather than a shell, which might have been made of cast-iron plates; or even wooden sheet piles would have been sufficient for the purpose, which was only a temporary one, if the concrete were really good.

Mr. Miller, in reply, said many opinions had been expressed as to the béton, and instances were cited of its setting hard, like solid rock, and requiring blasting afterwards to remove it, while in other cases failure had resulted. He was astonished that so much misapprehension should still exist as to this material. He could only account for it by supposing, that the compounds in prevalent use for common purposes, and also called concretes, were confounded with the béton, or hydraulic concrete, as applicable to marine construction, and he attributed the failures to the bad materials of which the concrete was composed. The many occasions in which concrete had been successfully employed in works of this description were sufficient to establish its value. Of course, in the preparation of béton, certain precautions must be observed. The materials must be properly selected, thoroughly manipulated, and duly proportioned to the work for which the béton was required. If those conditions were attended to, he considered that béton, whether made from the naturally hydraulic limes, or from artificial cements, such as Portland, or even the rich limes rendered hydraulic by the mixture of other substances, such as pozzuolana, would, as certainly as there was such a principle as chemical combination, be successful, and would set like solid rock; and that any cases of failure must have arisen from the want of attention to these principles. Many examples might be adduced of the deposit of hydraulic concrete in sea-water with perfect success; but it was unnecessary to go beyond the Greenock Sea Pier. The béton used in that work was made from materials obtained within a few miles of the spot, and it had set hard in a short time. It had been doubted whether the whole mass was consolidated throughout; but the answer to that was, that it had been often tested, by means of iron rods, which even shortly after it was put down would not pierce it. It had also been examined by divers, who, when it happened that too much was deposited in one place, preventing the granite blocks from being properly bedded, found great difficulty in picking it away. The best test, however, of the uniform setting of the concrete was to be found in the stability of the walls. It was only natural to expect, if there had been any irregularity in the setting of the béton, that the walls would have shown symptoms of settlement: but nothing of that kind had been noticed. With regard to the observations, as to the danger of depositing concrete in exposed situations, where it was apprehended the action of the waves might, to a certain extent, wash out the lime, leaving only the gravel and stones, he remarked that this would not take place unless the concrete was put down in thin layers, and in that state was allowed to be acted upon by the waves. It should not, however, be employed in that manner, but in large masses, and continuously; and though it was possible that some of the lime might be washed out from the surface, yet this would be replaced by the mass of béton that followed, so that the homogeneousness of the whole mass would not be injured. In illustration, he exhibited a specimen of the concrete, taken from the most exposed part of the Greenock Pier, which had been laid in a soft state, and was afterwards washed by the waves. In point of setting firm, nothing more could be desired. That concrete had been put down in a wet state, and was exposed to the action of the waves during the whole of the unusually stormy and severe winter of 1862-63, when several ships were driven from their moorings, in the vicinity of the harbour works, and the large steam dredger was wrecked on the new pier. This specimen showed that the danger to be apprehended from the washing out of the lime was not so great as had been supposed.

It had been remarked, that the system of casing adopted at Greenock did not give sufficient bond to the rest of the work. He quite agreed that, in many cases, it might be beneficial to adopt the system of bonding, and in fact it was upon that plan that the pier at Greenock was originally intended to have been built. However, the particular style of casing to be adopted would depend upon local circumstances, and upon the individual opinions of different Engineers. It was also said that, in any case, the facing could only be looked upon as a veneer, without proper connection with the rest of the work. He could not admit that; because it was efficiently held in position by the iron ties. Besides, he considered that if the concrete set thoroughly, as it would not fail to do if properly made, both it and the casing must together form a solid wall, as much as an ashlar facing did with a backing of rubble masonry in ordinary walls. As to the probable decay of the tie-rods, the great durability of iron when so imbedded was well known. But, whether or not, the tie-rods had only to serve a temporary purpose, inasmuch as when the concrete became consolidated they would not be required.

A great deal might no doubt be said for and against any new system of construction; but the best evidence of the plan advocated in the Paper was to be found in the success of the works already completed, and of that success it was open to any one who chose personally to satisfy himself, by paying a visit to Greenock. With regard to the application of the principle to the construction of breakwaters, he considered it had been sufficiently tested to justify the further extension of the plan; and it must be recollected that the Greenock sea pier was essentially a breakwater. In the construction of similar works in more exposed situations, it would only be necessary to make them stronger in proportion, and to take precautions according to the circumstances. There might be danger to the concrete from the action of the waves in a stormy sea; but he proposed to build the work in sections, with cross walls, or casings, at given distances, so that the facing and the béton work would be carried on together, and in that way the concrete would only be exposed to the wash from the surface, which he had shown was not very serious. Breakwaters had been constructed of timber frames filled with loose rubble stones, and these had withstood, successfully, the assaults of the waves. A structure of wrought iron with a stone casing, even though filled in with only loose rubble, would be much stronger than this; but when in addition the interior mass would be concreted like solid rock, he submitted that such a structure would combine all the conditions required for attaining the greatest stability and durability in the construction of breakwaters.

In pursuance of the notice on the card of the Meetings, it was proposed, and resolved unanimously:—

"That in order to insure a fuller attendance of Members than could be obtained on Easter Tuesday, the Meeting be adjourned until Tuesday evening, the 14th of April."

April 14, 1863.

JOHN ROBINSON M'CLEAN, Vice-President, in the Chair.

The following Candidates were balloted for and duly elected:—WILLIAM DENT DENT, M.A., JOSEPH FOGERTY, JOHN LEWIS, GEORGE WIGHTWICK RENDEL, and THOMAS CHARLES TOWNSEND, as Members; HENRY WILLIAM FERDINAND BOLCKOW, HENRY BOLDEN, OWEN BOWEN, CHARLES WILLIAM ROBERT CHAPMAN, JOHN DAVIS, CHARLES GOTT, CHARLES TOWNSHEND HARGRAVE, CHARLES LÖWINGER, RICHARD CHRISTOPHER RAPIER, and ALFRED RUMBALL, as Associates.

No. 1,090.—"Description of the Line and Works of the Scinde Railway."[1] By JOHN BRUNTON, M. Inst. C.E., F.G.S.

So far back as the year 1842 Sir Charles Napier, the conqueror of Scinde, acknowledged and publicly urged the vast importance of the valley of the Indus, as the route for military as well as for commercial communication with the Punjaub and the North-West Provinces of India. He never ceased to press upon the Government the necessity of establishing new modes of conveyance, and pointed out Kurrachee, then but a small fishing town, as the port to which the traffic would infallibly tend. Acting on this conviction, and as a first step towards carrying out these enlightened views and improving the port of Kurrachee, Sir Charles Napier designed and commenced the long mole across the tidal marsh, which separates the town of Kurrachee from Keamaree. This mole still bears his name; and at the point to which it had been carried when he left Scinde, and from which he embarked on that occasion, a small obelisk is erected recording these facts.

Nor has Sir Charles Napier been the only eminent man who has pointed out the natural advantages of the valley of the Indus, as the route of communication with the Punjaub and the North-West Provinces of India. Amongst the many who have recorded their opinions on the subject may be mentioned Lord Dalhousie, Sir Henry Pottinger, Sir John Lawrence, Sir Justin Shiel, General Jacob, and Sir Bartle Frere.

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[1] The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

In the year 1849 the Government recognised the necessity of introducing into India the improvements in communication which were offered by railways; and the two great lines,—the East Indian and the Great Indian Peninsula,—were inaugurated, with a view to open up the districts having the two great ports of India, Calcutta and Bombay, as the outlets for their produce. The success which attended the guarantee system, as affording facilities for raising the capital for Indian railways, was at once evident, and the importance of extending it to other districts was acknowledged.

Attention was immediately drawn to the Indus Valley route, having Kurrachee as its sea terminus; and a concession having been granted to Mr. W. P. Andrew in 1855, a company was formed, called the Scinde Railway Company, but embracing under its management not only the Scinde Railway proper, or the line from Kurrachee to Hydrabad upon the Indus, but the Punjaub line, from Moultan to Lahore and Umritsir, and a flotilla of steam boats on the river, with a view to complete the through communication. (Plate 10.) Three distinct capitals were originally raised, under the following titles:—1, The Scinde Railway; 2, The Indus Steam Flotilla; and 3, The Punjaub Railway. The accounts of these sections are kept perfectly distinct, while economy and harmonious working are secured, by the concentration of the management in the hands of one board of directors. Within the last three months, another section of this great scheme has been intrusted by Government to the Scinde Railway Company. It is called the Delhi Railway, being an extension of the line from Umritsir to Delhi, where it will form a junction with the northern terminus of the East Indian Railway. The lengths of these sections are respectively;—Scinde Railway, from Kurrachee to Kotree, on the Indus, 108 miles; Indus Steam Flotilla, Kotree to Moultan, 570;[1] Punjaub Railway, Moultan to Lahore, 222, Lahore to Umritsir, 32 = 254; Delhi Railway, Umritsir to Delhi, 300. Total, 1,232 miles.

It is to the construction of the first section of the line, between Kurrachee and Kotree, (Plate 12,) that this communication is specially devoted; and it is hoped that the facts thus recorded may be useful, not only to the Engineers whose professional labours may lie in India, but also to those Contractors who may find it their interest to undertake the execution of the great works which the extension of the railway system throughout India will infallibly render necessary. Although this section of the entire system is the shortest, it constitutes, as has been graphically observed, 'the neck of the funnel.' Over it must pass, not only the whole of the existing traffic, but as the other sections are completed, the developed commerce of this vast territory, hitherto locked up, will pour in upon it, taxing its capabilities as a means of communication, and, doubtless, realising the sanguine anticipations of its promoters.

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[1] This distance being measured upon the river is, on account of the windings, fully 100 miles more than the direct line by land.—J. B.

Kurrachee, the western terminus of the railway, is situate in lat. 24° 47′ 21″ and long. 66° 58′ 15″, and is not only the natural port of Scinde, but also of the Punjaub and of Central Asia. The plan, (Plate 11,) shows its form. Like many other land-locked harbours, it has the disadvantage of a bar at its mouth; but, nevertheless, the depth of water upon the bar at ordinary tides is sufficient to admit ships drawing 17 feet to 18 feet, and at spring tides, ships drawing 21 feet have passed in with safety. When once within Manora Point the depth of water is much greater, as is shown by the soundings upon the plan. The fast-increasing traffic of the port, and the large size generally of the vessels trading there, demanded that some measures should be taken to increase the depth of the water over the bar, thus rendering the entrance to the harbour available at all seasons; and that, by the erection of wharves and other appliances suggested by modern science, greater accommodation should be afforded. With this view her Majesty's Government, in 1856, applied to the late Mr. James Walker, F.R.S. (Past-President Inst. C.E.), for a Report upon the subject; and in 1858 he submitted plans, sections, and estimates for various suggested improvements. These recommendations were accepted by the Government, and immediate steps were taken for carrying them out. The groyne shown at A, (Plate 11,) is now advanced for about one-half its proposed length, and the result already is an increased depth of water on the bar. There is no doubt that when the works in progress are completed, Kurrachee Harbour will take a high rank as a safe and commodious port.

The population of the town of Kurrachee is about 60,000, and is rapidly increasing. The number of vessels entering and clearing outwards is shown in the following Table:—

Year.	Arrivals.		Departures.		Total.	
	No.	Tons.	No.	Tons.	No.	Tons.
1854–55	1,086	56,695	1,103	58,194	2,189	114,889
1858–59	1,589	131,311	1,654	138,176	3,243	269,487
1859-60	1,656	148,096	1,577	142,647	3,233	290,743

The principal articles of export consist of oil seeds, and grain of all sorts, wool, cotton, hides, indigo, munject, drugs and dyes, raw silk, fruit, and saltpetre. The import trade comprises cotton piece goods, woollen goods, malt liquors, railway materials, metals, wines and spirits, tea, coffee, timber, pipe staves and casks, regimental necessaries, spices, fruit, oilman's stores, and wearing apparel.

The following Table shows the increase of the import and export trade:—

Year.	Imports.	Exports.	Total.
	£.	£.	£.
1843–44	121,150	1,010	122,160
1844–45	217,700	9,300	227,000
1845–46	312,900	40,500	353,400
1846–47	293,400	49,300	342,700
1847–48	287,872	154,730	442,602
1848–49	344,715	107,133	451,848
1849–50	419,352	114,378	533,730
1850–51	425,831	196,461	622,292
1851–52	489,220	244,122	733,342
1852–53	535,690	376,337	912,027
1853–54	..	..	900,000[1]
1854–55	604,000	629,000	1,233,000
1855–56	628,913	604,440	1,233,353[2]
1856–57	685,665	734,522	1,420,187
1857–58	1,081,101	1,078,128	2,159,229
1858–59	1,540,605	1,044,272	2,584,877
1859–60	1,712,751	947,335	2,660,086[3]

Within the last two years, a large number of European and native mercantile firms have established themselves in Kurrachee, and have erected extensive warehouses, in order to meet the rapidly increasing trade of the port. Her Majesty's Government has found it necessary to erect a new and more commodious Custom-house; and the harbour improvements now in progress include not only the deepening of the water on the bar, but greatly extended wharf and quay accommodation. The Scinde Railway will communicate directly with these wharves and landing places, and a great improvement in the system of loading and discharging cargoes has already been introduced, and is daily making rapid strides.

Hitherto all commercial communication with the upper districts has been carried on by native boats on the Indus, or by cafilahs of camels. No roads worthy of the name exist. Until the opening of the Scinde Railway these river boats were accustomed to stop at Khettie, a river station at one of the mouths of the Indus, (Plate 10,), and there discharge their cargoes into native sea-going craft, which conveyed the greater part to the port of Bombay, only a comparatively small portion reaching Kurrachee. The import trade had to struggle with the same impediments, increased by the slow progress made in 'tracking' the boats up the Indus, against an average current of 3 miles, or 3½ miles per hour, and a portage at Sukkur of 1½ mile. During the prevalence of the south-west monsoon, lasting from May to September inclusive, even this wretched and dilatory system was suspended, paralysing commerce and creating an indescribable amount of expense, inconvenience, and irregularity. The formation of the Scinde Railway, and the improvement of the port of Kurrachee, have met all these obstacles, and will open up a magnificent field for commercial enterprise, introducing civilisation, with all its attendant benefits, to a district inhabited by millions of human beings hitherto shut out from its influences.

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[1] There are no exact returns of the sea trade for 1853-54.

[2] This return is for eleven months only.

[3] The trade of 1862–63 has amounted to £3,500,000 in the nine months, and is estimated at £5,000,000 for the whole year.

On the 29th of April, 1858, the works of the Scinde Railway were commenced by Sir Bartle Frere, K.C.B., then the highly-respected Commissioner of Scinde, who wheeled the first barrow-load of earth into an embankment in the neighbourhood of Kurrachee. The contract for the execution of the whole of the works was originally let to Messrs. James and Edwin Bray; but in June, 1859, the line was taken over by the Company, and the works then remaining to be completed were executed departmentally by the Engineers, Inspectors, and other officers of the Company. Without entering into a statement of the causes of Messrs. Bray's relinquishing the works, which at present form a subject of legal reference, it will suffice to say, that when the Company's Engineers took possession of them, they had to encounter difficulties which were not due entirely to the peculiarities of the country. There was a great dearth of the ordinary railway plant: irregularity in the payment of the native labourers of all classes had driven many away, and had caused an unnatural and serious rise in the rate of wages. To meet this position of affairs, and to secure the economical execution of the works, a fair tariff of wages, at a reduction of fully 25 per cent. upon those which were paid by Messrs. Bray, was published by the Company's Engineers, and daily payments were guaranteed. This had the effect of drawing a considerable number of labourers to the undertaking.

The Province of Scinde contains but a sparse population, which is principally located on the low-lying alluvial land on the banks of the river, where the rich earth yields ample returns with a minimum amount of labour. The Scindee, born and bred on these plains, is naturally indolent and devoid of muscular power; at the same time he is not deficient in talent, easily acquiring a knowledge of account-keeping and writing. The natives of the neighbouring state of Cutch are a much superior race. Cutch sends carpenters, masons, smiths, and skilled handicraftsmen to the whole of the northern portion of the Bombay Presidency; and from thence came a large majority of the skilled workmen employed on the Scinde Railway. From the hill tribes of Beloochistan and Affghanistan were obtained a hardy race of labourers; men of great stature and personal strength, but wholly ignorant of the use of other tools than the powrah, (a large kind of hoe,) and a basket in which to carry the loosened earth. Half-wild and unaccustomed to the restraints of a more civilised state, these men required much tact, and at the same time a strong arm, to keep them in order. To secure and maintain discipline amongst such a body of men, it was found advisable to organise a regular railway police force, consisting of about 80 men. Police stations were erected at intervals along the line. To facilitate the administration of justice the Government appointed a special magistrate, whose duty it was to move up and down the line, and to hear any cases which might be brought before him. To these wise precautions may be attributed the fact, that few outrages of a serious character occurred, the majority of cases being petty thefts and attempts at imposition. This facility for obtaining justice, and the rapidity with which punishment followed crime, were highly appreciated both by the Europeans and the natives.

In districts like Scinde, where the population is scanty, and it becomes necessary to depend upon distant provinces for the supply of labour, it is obviously wise policy to offer every inducement, not only to secure, but to maintain such a supply. A higher rate of wages than ordinary may, in the first instance, draw together large bodies of men, but other arrangements are absolutely essential for establishing contentment and permanence. Hardy as these Beloochees and hill tribes were, and unaccustomed to anything approaching luxury, they appreciated highly such attentions to their feeding, shelter, and health, as policy no less than humanity suggested. When it is borne in mind, that the course of the line of railway lay at a considerable distance from existing towns, or villages, only passing through the small village of Jemedar-ke-Landi, and leaving the important towns of Tatta and Jerruck at distances of 10 miles and 17 miles respectively,—it will be seen, that a difficulty arose in obtaining food for the large masses of men congregated at the various heavy portions of the works. This was met by the Company licensing a number of bunians, or native provision merchants, to establish themselves at various points along the line; their scales of charges being regulated by a nerrick, or list of prices, settled by the nearest kardhar, under the orders of the railway magistrate. To supply the workmen with wholesome water for drinking was equally imperative. When this precaution was not observed, the men were under the necessity of using such water as was most easily accessible, and as it was generally of very bad quality, the results were cholera and fever of a bad type. A regular system of water carts and bullocks was first organised, and as the railway progressed, water trains were dispatched from the Mulleer, the Indus, and the Bahrun, to meet the daily requirements of the men. It was remarked, that a supply of wholesome water was always followed by the disappearance of the diseases above-mentioned, and more particularly of fever. To protect the men from another source of fever, mat huts were erected, which sheltered them from the heavy dews, and rendered them more comfortable and contented. To afford medical aid in cases of sickness, or of accident, permanent hospitals were erected at Kurrachee and Kotree, under the charge of the civil surgeons of these stations; and in addition, two temporary hospital buildings were erected at Joong Shaie and Doraji Gore, under the charge of a resident apothecary. These arrangements were very successful in preserving the health of the employés of the Company, both European and native, and in cases of accident, they were doubtless the means of preserving many lives.

The natives work in gangs, under a self-elected muccadum, or ganger, whose orders they cheerfully obey, and to whom each man pays a stipulated small per-centage from each rupee earned by him. It is through the muccadum, or ganger, that all agreements are made for work, and it is he who receives the amount of the earnings for division. There exist also, in Scinde and in the neighbouring States, native landholders who, by inheritance, are chiefs of large districts of country, and are recognised by Government as possessing a sort of feudal right therein. They are heads of clans, and as there is no longer any necessity for summoning their vassals for defence, or for other less lawful objects, they find it their interest to use their power for the purpose of supplying labourers to any large public work, receiving a small remuneration in the shape of head money. In the year 1856, while acting as Commissioner in Scinde, during the temporary absence of Sir B. Frere, General Jacob, recognising the demoralising influences which attended the system of compulsory labour, proclaimed all labour in Scinde to be free. This edict is highly prized, though sometimes taken advantage of and abused, by the labouring classes.

The departmental execution of the works gave the Engineers and other officers engaged, favourable opportunities of becoming acquainted with the capabilities of the various classes of natives, as well as of ascertaining the cost of each description of work. When work of any kind was executed by day labour, it was found that its economical execution entirely depended upon the energy and honesty of the muccadum, or native overseer; but these good qualities were so rare, that it became necessary to resort to the piece-work system. It was with some difficulty that this was established as a rule; but by degrees opposition was overcome, and the earthwork, masonry, and ballasting, were let to small gangs, with considerable advantage to the Company, while the labourer himself, excited to more vigorous and diligent exertion, earned higher wages than by the day-work system.

The following are the average prices paid for earth and rock work along the line:—

Alluvial earth excavated from side trenches and placed in embankment, the average distance of conveying it being 22 yards . . .	10 annas per 100 cubic feet, or 4·09 pence per cubic yard.
Firmly set gravel, or soft shaly material . .	12 annas per 100 feet, or 4·9 pence per cubic yard.
Rockwork requiring bars, but no powder for blasting	1*s.* 9*d.* per cubic yard.
Hard rock requiring blasting,—the powder, drills, and other tools being found by the Company	2*s.* 0*d.* „ „
Ballast, consisting of small stones, or gravel, gathered in the neighbouring jungle, selected and placed *in situ*	1*s.* 0*d.* „ „
Ballast of broken stone	1*s.* 10*d.* „ „

The total quantities of the different classes of work executed upon the line, and the average cost of each kind, inclusive of the cost of the provisional staff of superintendents, but exclusive of that of the permanent Engineering staff, are given in the following Table:—

Description of Work.		Quantity.	Average Cost.		
			£.	*s.*	*d.*
EARTHWORK.					
Embankments	cubic yds.	1,831,916	0	0	11½
Cuttings (a large portion consisting of rock of different degrees of hardness) . .	,,	432,705	0	1	6¾
Diversion of roads and streams	,,	212,532	0	0	8½
Ballasting	,,	408,596	0	1	6
Pitching slopes	sup. yds.	1,745	0	2	0
PERMANENT WAY.					
Leading and laying.	lineal yds.	193,600	0	6	0
FENCE WALLING	,,	338,700	0	3	0
MASONRY.					
Concrete	cubic yds.	10,756	0	4	6
Dry rubble	,,	2,526	0	3	0
Common ditto	,,	17,434	0	12	0
Coursed ditto, with rubble backing	,,	352	0	15	0
Coursed ditto	,,	32,550	1	0	0
Block in course	,,	15,192	1	11	6
Ashlar	cubic feet	87,806	0	1	7½

The geological character of the district traversed by the Scinde

Railway demands a few remarks. The aspect of the country generally is barren in the extreme, but in some places there is sufficient soil to repay cultivation. Situated in what is termed the rainless zone, the average quantity of rain is very small. The annual rainfall from 1855 to 1860 is given in the following Table:—

Rain Measured at the **Observatory** of the **European Hospital**, **Kurrachee**, from the 1st September, 1855, to the 31st August, 1860.

Year.	September.	October.	November.	December.	January.	February.	March.	April.	May.	June.	July.	August.	Total.	
1855	0·15	0·00	0·00	0·00	..	..	..	..	..	..	..	..	0·15	
1856	0·00	0·00	0·00	0·00	1·62	0·59	0·00	0·00	0·00	0·04	0·11	0·25	2·61	4·82 Average.
1857	0·38	0·00	0·00	0·00	0·41	1·13	0·00	0·00	0·00	0·00	0·29	4·34	6·55	
1858	0·57	0·00	0·00	0·27	0·00	0·00	0·00	0·00	0·00	0·03	4·94	0·09	5·90	
1859	1·08	0·00	0·02	0·20	0·00	0·00	0·02	0·00	0·00	0·00	4·90	0·00	6·22	
1860	0·00	0·00	0·00	0·00	1·09	0·00	0·00	0·00	1·22	0·00	0·00	0·52	2·83	

Kurrachee, 31st August, 1860. (Signed) C. Richtern,
Observer.

The rain is looked for about the 20th of July. Except during the rainy season, the river beds are dry, but in them water can generally be obtained, by sinking to depths varying from 5 feet to 30 feet. All the water procured from these wells is, however, more or less saline. The following analysis of several samples was made at the Government laboratory, Bombay, and will show to what extent this property prevails:—

Table 1.

The Numbers indicate parts in 10,000 of Water.

	A	B	C	D	E	F
Specific gravity . .	1000·72	1000·54	1000·44	1000·75	1001·10	1000·69
Carbonate of lime .	1·160	1·328	1·252	1·720	1·011	1·136
,, magnesia	·908	·757	·621	·247	1·151	1·120
Lime	·241	·333	·161	·611	·257	·289
Magnesia	·210	·113	·187	·269	·037	·135
Chlorine	2·281 ·825	1·598	1·731	2·281	2·689 1·473	2·130
Chloride of sodium .	4·445	2·485	2·185	Not tried.	Not tried.	Not tried.
Silica & oxide of iron	·100	·310	·386	·756	Not tried.	Not tried.
Sulphuric acid . .	·334	·601	·479	·851	·741	·896

TABLE 2.

SOLID CONSTITUENTS IN WATER marked B, in 10,000 parts.

Chloride of sodium	2·485
Sulphate of lime	·809
Chloride of magnesium	·115
Sulphate of magnesia	·188
Carbonate of lime	1·328
,, magnesia	·757
Silica and oxide of iron	·310
Total	5·992
Total solids by evaporation .	5·490

TABLE 3.

	WATERS AT KURRACHEE, (selected).				
	21	22	23	24	25
	Bed of Lyaree River.	Campwater, Company's well, near Government Gardens.	Well on the Bunder Road, in front of Messrs. Warwick and Waller's premises.	Well on the Bunder Road, near Muchee Meanee.	Well in the Rutton Tank.
	H	H	H	H	H
Date of Collection . .	June, 1859	June, 1859	June, 1859	June, 1859	June, 1859
Specific gravity at 60° Fah.	1000·4	1000·9	1006·6	1037·8	1001·4
Chloride of sodium . .	2·35	8·12	58·20	423·75	9·41
,, magnesium .	·02	—	—	—	—
,, calcium . .	·66	—	—	—	—
Sulphate of soda . . .	—	·78	4·34	43·73	2·02
,, magnesia .	—	·05	6·61	76·85	·02
,, lime . . .	·53	·69	·44	12·04	·45
Nitrate of magnesia . .	—	—	—	—	—
,, lime . . .	—	—	—	—	—
Carbonate of magnesia .	·04	·38	1·09	2·91	·95
,, lime . .	·55	·96	2·37	2·37	1·26
Silica	(X)	(X)	(X)	(X)	(X)
Organic matter in solution	—	—	—	—	—
,, ,, suspended	—	—	—	—	—
Total solids. . .	4·15	10·98	73·05	561·65	14·11
Gaseous contents .	—	—	—	—	—

Samples Nos. 21 to 25 were selected from nineteen specimens taken from all the wells and tanks in use at Kurrachee. The difference in the quality of the water is extreme. Nos. 21, 22, and 25 are fair drinkable waters. In No. 23 salt is present in enormous quantity, the water being a strong brine, twice as salt as sea water. The purest water was obtained from the River Indus at Kotree, and from wells in the bed of the Mulleer.

In the neighbourhood of Kurrachee, the principal features of the country are low hills, varying from 150 feet to 200 feet in height, and consisting of a coarse-grained arenaceous rock, of a dirty yellow colour, abounding with fossils. Most of these hills are capped with conglomerate, more or less disintegrated on the surface, the pebbles composing it being water-worn, and the majority derived from the nummulitic limestone of the Halla range of hills, which extend from Cape Monze, in a north-easterly direction, to the west of Mithun-Kote on the Indus. All the hills lying north of the Indus to the foot of the Halla range, of which they are spurs, exhibit the effect of considerable volcanic disturbance, and the drainage of the country passes through the fissures thus formed. One of the most remarkable of these is at Dhurwat, where, during the rains, the water of the Bahrun occasionally rises 70 feet, rushing through the pass with overwhelming force. The Kheytriani hills are composed of pale arenaceous limestone, containing but few nummulites. This rock is easily worked, and is an admirable building stone, hardening with exposure. It was from quarries opened in this neighbourhood, that most of the stone was obtained for the masonry of the central district of the line. Near the Rhodh River there are many small hills, of conical shape, composed of calcined clays of various colours, and also large collections of nodular masses of flint. In the aluminous clay beds, veins of foliated gypsum abound. In the plains lying between these hills the soil is alluvial, and in many places it is covered with boulders of nummulitic limestone and conglomerate. The following Table, taken from a letter addressed to Sir R. I. Murchison by Captain N. Vicary, of the Hon. East India Company's service,[1] will serve to give a general idea of the relative position of the formations existing in Scinde:—

1. Conglomerate.
2. Clays and sandstone.
3. Upper bone-bed.
4. Sandstone; fossils rare.
5. Lower bone-bed.
6. Coarse arenaceo-calcareous rock with *Cythorea exoleta* and *exarata*; Spatangi; no Nummulites.
7. Pale arenaceous limestone, with Hypponyces, Nummulites, and Charoideæ.
8. Nummulitic limestone of the Halla Range.
9. Black slates, thickness unknown.

The fact that indications of considerable volcanic disturbance are visible among the ranges of hills lying to the north-east of the line of railway has been already noticed. At 3 o'clock in the morning of Tuesday the 9th of April, 1861, a rather smart shock of an earthquake was felt at Kurrachee, and at several places along the line, which occasioned some cracks in the walls of the Author's house in Kurrachee; and those observed shortly after, in some of the masonry of the bridges along the line, may be referred to the same cause. It is, therefore, suggested that, to guard against the consequences of such an event, hoop-iron bondings should be introduced into the walls of future buildings. This would be attended with but small extra cost, and it is submitted that such a precaution on other lines of railway in India may not be unadvisable. The natives of Scinde and Cutch possess legends of the occurrence of violent earthquakes; and though there is no authority for it, the utter prostration of the extensive buildings of Brahminabad, 60 miles east of Hydrabad, may lead to the inference, that an earthquake completed the ruin of that once important city.

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[1] *Vide* "The Quarterly Journal of the Geological Society of London," Vol. iii. p. 335. London, 1847.

The distance between Kurrachee and Kotree traversed by the Scinde Railway is 108 miles 10 chains. Of this distance 32 miles 50 chains are level, and the remaining 75 miles 40 chains are on inclines more or less favourable, 1 in 200 being the ruling gradient, as will be seen by the following classified abstract of the gradients:—

From	To	Length.	
		Miles.	Chains.
	1 in 200	10	27
1 in 200	1 ,, 300	22	33
1 ,, 300	1 ,, 400	15	67
1 ,, 400	1 ,, 500	5	5
1 ,, 500	1 ,, 600	3	48
1 ,, 600	1 ,, 700	6	63
1 ,, 800	1 ,, 900	3	10
1 ,, 900	1 ,, 1,000	3	8
	1 ,, 1,056	1	0
	1 ,, 1,100	2	31
	1 ,, 1,402	0	68
	1 ,, 1,760	1	0
Total length of gradients		75	40

The total length of straight line being 74 miles 22 chains, the length of the line on curves is, therefore, 33 miles 68 chains, the sharpest curve having a radius of 43 chains for a distance of 76 chains, as will be seen by the following Table:—

Radius from	To radius	Length.	
Chains.	Chains.	Miles.	Chains.
	43	0	76
57	100	9	15
115	200	22	50
240	320	1	7
Total length of curves .		33	68

Considering the nature of the country traversed by the line, these may be considered favourable features, and place it in a good position for being worked at a moderate cost.

The earthworks generally are executed to accommodate a single line of railway; but all the bridges, culverts, and stone viaducts are constructed to carry a double line. In the cases of the wrought-iron viaducts, the stone piers are adapted to support girders for a double way, while those required for a single line alone are erected. The only portion of double line yet made, is that between the workshops at Ghizree Junction and the terminus at the Bunder Head, a distance of 3 miles 15 chains. In order to accommodate the traffic coming to Kurrachee from the districts called the Eastern Delta of the Indus, during the south-west monsoon, a short branch, 3½ miles in length, has been constructed, leaving the main line near the workshops, and terminating in an embankment and a timber pier at Ghizree, alongside which native boats discharge their cargoes. The permanent way consists of the ordinary double-headed rail, weighing 65 lbs. per yard, fixed by compressed wooden keys in chairs, each weighing 22 lbs. The joints are fished in the usual way, the fish plates being secured by four bolts, each 1 inch in diameter. The whole is laid on transverse wooden sleepers, at intervals of 3 feet, except at the joints, where the sleepers are only 2 feet apart. The dimensions of the sleepers are:—length, 10 feet; breadth, 10 inches; depth, 5 inches. A large proportion of the sleepers is of red and white pine creosoted, sent from England. To complete the requisite quantity, a contract was entered into with a native merchant at Lahore, for the supply of sleepers of deodar timber, (*Cedrus deodara*,) which grows upon the slopes of the Himalayas, where it attains great size. Several logs sent down to Kotree for the use of the railway measured 5 feet in diameter at the butt, and a calculation of the taper upon the log gave a result of 150 feet as the height of the tree. The trees are felled, and cross-cut into convenient lengths, for rolling to the bottom of the ravines, on the banks of which they grow. The private mark of each proprietor is cut on every log he has felled. These logs remain at the bottom of the ravines until the rains, when they are carried by the torrents into the River

Indus, where they are watched for, selected according to the marks, rafted, and floated to their destination. This rough treatment wastes much of the timber; many of the logs are split, and the ends of all are damaged; while the shortness of the pieces, which vary from 20 feet to 33 feet in length, diminishes their value. Owing to the deficiency of rain in the season of 1859-60, only a small quantity of this timber could be got down. The native merchant thus failed to complete his contract; and a quantity of Australian blue and white gum, and native red eyne sleepers was, therefore, purchased. These were objectionable, on account of their great weight, and the ease with which they were split by the driving of the spikes. The respective cost of each, when delivered in Kurrachee or Kotree, was:—

	Delivered in Kurrachee.	Delivered in Kotree.
	s. d.	*s. d.*
Creosoted pine	8 11	..
Australian blue gum . . .	8 0	..
Eyne, a native timber . .	7 9	..
Deodar	..	6 0

The value of the deodar timber is becoming rapidly recognised, and means will, doubtless, be adopted for supplying it in longer lengths, and in greater quantities. When first cut it possesses a very strong scent, which it retains for some years; and to this probably may be attributed its immunity from the ravages of the white ant, which does not attack it until the timber has to a great extent lost this scent. To protect the deodar sleepers from these attacks, and before the Burnettising apparatus was received from England, they were steeped in a solution of sulphate of copper. This proved to be an unfailing specific; but it possesses this serious objection, that iron nails or spikes driven into timber thus prepared are rapidly destroyed by the action of the sulphuric acid. The result of the Author's experience, with reference to the important question of sleepers, is that pine sleepers, whether red or white, imported from England and creosoted, are liable to split and twist to a great extent, probably on account of the extreme dryness of the climate. They also become very brittle, the nature of the timber being destroyed. The creosoting process only penetrates a certain distance from the surface of the sleeper; and so long as the sleeper does not split, the creosote effectually protects it from the attacks of the ant, but immediately a part of the interior becomes exposed, the ant attacks it, and soon destroys the uncreosoted core of the sleeper. Hitherto, the necessity for replacing sleepers has mainly arisen from their giving way by splitting, rather than from any damage by the attacks of the white ant, or from ordinary decay. The excellent ballast on the Scinde Railway, consisting chiefly of broken stone or clean gravel, assists in preserving the sleepers from the white ant.

The cost of creosoting sleepers in India varies with the description of timber submitted to the operation. In 1854 Mr. Turnbull, Chief Engineer of the East Indian Line, gave the following summary of the details of the cost supplied in a former portion of his Report[1]:—sâl, 6½*d.*; teak, 1*s.*; soondry, 1*s.* 5½*d.*; and sissoo, 2*s.* 1½*d.* per sleeper. He further states, in the same Report, that one thousand sleepers of fir wood, prepared by Sir W. Burnett's process with chloride of zinc, were landed and stacked in Calcutta, where they remained for two years. On being examined at the end of this period, they were all found to be sound, and in as perfect a condition as when they were landed. This statement led the Author to recommend the adoption of Sir W. Burnett's process, and a complete apparatus was shipped from England. The vessel was, unfortunately, lost on the passage; and considerable delay occurred in replacing the apparatus, so that the majority of the deodar sleepers were submitted to the sulphate of copper process. The cost of the Burnettising process at Kotree is 5½*d.* per sleeper, which contrasts favourably with the cost of creosoting.

The forests of Scinde consist chiefly of babool, a species of acacia, of which there are two kinds, red and white, so named from the respective colours of the heart wood. The former is by far the more valuable of the two, as it is extremely hard, and resists the attacks of the white ant. This timber is used by the natives for the manufacture of carts and Persian wheels; but as it is very crooked, it is not available for railway sleepers. A few pieces of timber were carefully selected, and accurately gauged to size, with a view of testing their comparative strengths, but the experiment was not carried out. When thoroughly seasoned, the following comparative Table of the weights of each kind was obtained:—

Red eyne	56¼	lbs. per cubic foot.
Jarrah (Australian mahogany) .	52¼	" " "
Common jungle teak	34½	" " "
Moulmein teak	33¾	" " "
Deodar	31½	" " "
Yellow pine	24¾	" " "

Neither eyne nor jarrah timber will float in sea water before it is thoroughly dried. Red eyne is obtained from the forests of Guzerat, and costs in log, delivered in Kurrachee, about 1*s.* 6*d.* per cubic foot. It is not, however, very plentiful. As a pile it drives remarkably well, hardly requiring either ringing or shoeing in ordinary ground. It is reported to be impervious to the attacks of the white ant; but of this the Author has no positive proof. The Moulmein, or Rangoon teak, judging from the quality of the best the Railway Company could procure, is inferior to the southern, or Malabar teak, which, however, is scarce and expensive. The cost of Moulmein teak in log, delivered in Kurrachee, varies from £15 to £18 per load. The jarrah is a fine Australian timber, and is obtainable in logs of large scantling and length. If not well seasoned before being submitted to the dry climate of Scinde, it cracks and rends seriously, but not so if it is allowed to season for twelve months before being shipped. Its cost in Kurrachee is about 1*s.* 6*d.* per cubic foot. The deodar timber, the qualities of which have been before adverted to, costs at Kotree in log about 1*s.* 1*d.* per cubic foot.

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[1] *Vide* "Selections from the Records of the Madras Government. Report of the Railway Department for 1854," page 238.

The majority of the fencing used on the Scinde Railway consists of a dry rubble-stone wall, having a coping of stones on edge, set in mortar. Its height is 4 feet above the surface of the ground. Its thickness at the bottom, just above the footings, is 1 foot 10½ inches, and at the top 15 inches. Its average cost was 3*s.* per lineal yard. Along 15 miles of the line, between Jemedar-ke-Landi and Guggur, five-strand wire fencing was adopted, on account of the distance of suitable stone, and the necessity for its rapid completion. Its cost was 2*s.* 4½*d.* per lineal yard. The cost of maintenance of the wire-fencing is high, compared with that of the stone wall.

At Kurrachee, the locomotive erecting and repairing shops are built, at the junction of the Ghizree branch with the main line. These works consist of a sawmill, smiths', fitters', heavy and light tool shops, iron and brass foundries, with engine and carriage-erecting shops, all furnished with the requisite machinery, and with tools driven by engine power. Previous to the establishment of these works, there existed no means, nearer than Bombay, for the execution of the necessary repairs, or the construction of the numerous articles required by a railway; and even Bombay offered but few facilities, and those involving great expense. Hence the necessity for pushing forward these works, which, in the formation of the line, proved to be of great assistance in the manufacture of plant, &c. The organisation of these works, with a view to their ultimate utility, and at the same time, with a due regard to economy, formed an important consideration, and was surrounded with many difficulties. To man these shops entirely with European workmen would involve an enormous cost; it became necessary, therefore, to call in native assistance, as far as practicable. The Cutch carpenters and smiths, as has been before remarked, are intelligent and excellent workmen; but they were wedded to the use of their own rude tools, in their own fashion, involving great delay in turning out work. Their usual method is to carry on all operations while seated on the ground; and, in the case of the carpenters, to make almost as much use of their toes as of their fingers. It became, therefore, the duty of the English foreman to induce them, first of all, to stand to their work, and then, to teach them the use of European tools. This has been accomplished by degrees, and the result has been most satisfactory. The carriages now framed and erected at these shops, entirely by Cutch carpenters, display workmanship which would be a credit to the best European manufactory. It is found necessary still to employ two European smiths for heavy and important work.

To keep up a supply of European foremen, fitters, engine erecters, and engine drivers, the system of taking apprentices in the workshops has been adopted. The following liberal terms were offered :—

During 4 months' preliminary trial,		per mensem	4	rupees or	8s.
First year from date of indentures,		,,	30	,,	£3
Second	,, ,,	,,	40	,,	4
Third	,, ,,	,,	50	,,	5
Fourth	,, ,,	,,	60	,,	6
Fifth	,, ,,	,,	80	,,	8

In India there are many intelligent lads, sons of European soldiers and of men employed in various departments of the Government service as clerks, &c., who are educated in the regimental and Government schools: these lads and their parents are very glad to avail themselves of the opening thus offered for learning a trade, and obtaining substantial employment. By this arrangement a staff of men, thoroughly acclimatised, is being educated in all branches of railway mechanism, and without doubt great advantages will, in a few years, accrue therefrom.

The electric telegraph, with two lines of wires, is laid along the Scinde Railway. The wires are carried upon posts of deodar timber, fixed in cast-iron sockets. The block system of working the trains is adopted. Needle-speaking instruments are used for conveying the information required between the several stations and passing-places. On the Continent of Europe there exists but little difficulty in obtaining suitable and intelligent clerks for working the telegraph signals; but in India the case is widely different. There, for the sake of economy, the staff of telegraph clerks is formed and recruited from the class of half-castes and more intelligent natives, very often lads of fourteen or fifteen years of age. It is true they have to pass a preliminary examination as to their capabilities in writing and reading English; but the Author's experience of men who have passed this examination is, that they are often deficient in the important point of understanding the messages they transmit or receive. This becomes a more serious matter when the signalman, a native, is trusting to the verbal instructions he receives from the telegraph clerk, who, in several instances on the Scinde Line, holds the combined offices of telegraph clerk and station master, a system which, for many obvious reasons, is to be deprecated. Greater security would be obtained by the separation of the train-signalling machine from the conversing telegraph, and also by the introduction of permanent train-signals, which would speak to the eye, and could not be liable to misinterpretation. Native clerks are too apt to occupy the speaking-machine, and at the same time to amuse themselves with a conversation, to the exclusion or the delay of important messages.

In India, train-signalling stations, on which depend the proper and safe working of the trains, are often in isolated situations, and economy only allows the maintenance at each station of one signalling-clerk, who may often be taken ill with fever, or otherwise be rendered unable to perform his duties. The reduction of the train-signalling to as simple a system as possible, and the training of all policemen and inspectors in the use of the instrument for this purpose, would be attended with much benefit.

The line of the Scinde Railway, as will be seen by the map, (Plate 12,) crosses the natural drainage of a great extent of country, thus rendering necessary a large provision for waterway. The rains in Scinde are very partial, and as there are no records of rainfall which throw much light upon the subject, and no existing bridges, a careful examination of old flood marks was the only guide as to the requirements. Fixing the spans of the bridges at the large rivers and nullahs was comparatively easy. It was in crossing wide, flat plains, such as that at Pipri, that the question was surrounded with difficulties. This plain is nearly 5 miles wide. A certain number of culverts was originally built, and in addition, large catch-water drains were cut, with a view of conducting the rain water to the Guggur River, the natural and main drain of the valley. In 1861, when the rain was very heavy for about six hours in this locality, the drains were found insufficient to carry off the water in the time, and the embankment of the railway, which ponded up the water, was soon breached in many places. To remedy this, it was considered a waste of money to erect more culverts; but the plan was adopted of lowering the line to the surface, laying it, in fact, in a ditch 16 feet wide and 2 feet deep, just large enough to receive the ballast, and allowing the water to flow over the line. This plan was severely tested in the unusually heavy rains of 1862, when the water passed over the rails to the depth, in some places, of 9 inches, without either damaging the line, or stopping the traffic. In districts like Scinde, where the rainfall is so partial, and of such short duration, but at the same time so heavy, it is submitted that this mode of crossing a large, flat plain is the safest and most economical.

The scarcity of pure water fit for use in the locomotive engines, except at a few points, caused considerable trouble on the first opening of the line. The watering stations are nine in number. The salts, which the water obtained at these stations held in solution, differed materially, and the consequence was, that if an engine started from Kotree, and took in water at Jheem Peer, or Joong Shaie, priming occurred to a serious extent; but this was not the case if water was taken at the Bahrun. As the water at these stations was considered fair drinking water, and as there was nothing in the taste to induce the suspicion that they might not be used indiscriminately for locomotive purposes, it would appear desirable, that a careful analysis of the water obtainable along a line of railway in India should be made at an early stage of the operations. The Author has arranged that the waters used and obtainable upon the Scinde Railway should be analysed, and when combined with a report upon the effects produced in the locomotive engine by mixing them, some useful information will be obtained for guidance in parallel cases. When completed, it shall be submitted to the Institution.

The haulage of materials constitutes an important item in the cost of the construction of railway works everywhere, and especially in India. The following facts will assist in forming calculations on this head. About 5,500 tons of permanent-way materials were required at Loyach, one of the stations on the line, and were conveyed by native boats from Kurrachee to Soondah, a point upon the River Indus where there was a convenient landing place. It was necessary to form a road for carts between Loyach and Soondah, through the jungle, a distance of 12½ miles, and the following were the details of the cost of the whole proceeding:—

Freight from Kurrachee to Soondah by native craft, including cost of loading and discharging cargo . . .	8*s.* 6*d.* per ton.
Loading and unloading the native carts .	0*s.* 6*d.* ,,
Haulage 12½ miles, at 1*s.* per ton per mile	12*s.* 6*d.* ,,
The cost of forming and maintaining the road for twelve months was £323. 13*s.* 6*d.*, equal on the above-mentioned quantity of materials to	1*s.* 2¼*d.* ,,

The following is a list of the different-sized culverts erected on the line, distinguishing the number of culverts, and the number of openings of each size:—

Number.	Size of Opening.	Number of Openings.
46	2 feet 6 inches	191
2	3 feet	2
2	6 feet	2
113	8 feet 6 inches	329
5	10 feet	9
18	12 feet	53
2	15 feet	2

The line of rails was carried over the openings of 2 feet 6 inches, by placing ordinary sleepers upon stone piers, the rail itself bridging the opening. Though this appears to be an economical mode of obtaining waterway through low embankments, it was found that the vibration of the line was communicated to the piers, which, though very carefully built, thus required frequent repairs, and in some cases cramping. Whenever the height of the embankment would admit of it, and to secure the largest amount of waterway, openings of 8 feet 6 inches were extensively introduced. In such cases the ordinary permanent way was carried upon teak timber beams, 12 inches square in section, supporting a platform of planks 4 inches thick below the sleepers, to carry a thin layer of ballast, protecting the platform from fire, and forming a footway across the openings. The timber in these culverts was carefully paid over with dammer, or pitch, laid on very hot. This process protects the timber from the attacks of white ants, but it is objectionable on account of the inflammable character of the material. The other culverts in the list were built of stone, with pitched inverts and aprons.

The bridges along the line are of the following number and general dimensions:—

19	bridges,	containing	48	arches,	each of	20	feet span.
1	,,	,,	3	,,	,,	30	,,
2	,,	,,	10	,,	,,	40	,,
2	,,	,,	4	,,	,,	45	,,

The large stone viaduct across the Bahrun River is 1,728 feet in length. Its greatest height, measuring from the bed of the river to the rails, is 31 feet 6 inches, and its average height is 25 feet 6 inches. The superficial measurement of the bridged area is 44,064 square feet. It consists of thirty-two arches, each 45 feet span, and having a rise of 10 feet 6 inches. This was the heaviest piece of masonry upon the line, and the time required for its completion was the measure of that for the opening for public traffic. The quantities of the different classes of work in this viaduct, and the average cost of each kind, (full details of which are given in the Appendix, page 475,) are as follows:—

	Quantity.		Cost. s.	d.	
Excavation of foundations	20,513	cubic yards	0	9¼	per cubic yd.
Concrete	6,814	„	4	0¾	„
Common rubble	4,455	„	11	9¾	„
Coursed rubble	7,233	„	20	0¾	„
Block in course	5,244	„	31	6	„
Ashlar	29,000	cubic feet	1	3	per cubic foot.
Broken stone for backing and filling in between the spandrils	2,650	cubic yards			
Ballast	3,780	„			

The total cost of this viaduct was £27,185. 12*s.* 10*d.* The cost per lineal foot of viaduct was £15. 14*s.* 7*d.*, and per square foot of bridged area 12*s.* 4*d.* The viaduct was commenced on the 5th of March, 1859, and a locomotive engine ran over it on the 26th of January, 1861. The work was thus completed in twenty-two months and a half.

There are six viaducts with iron girders. The girders sent out from England were on Warren's principle, of 80 feet clear span. These were erected at the following rivers:—

The Mulleer	21	spans.
„ Guggur	3	„
„ Dorbagi	2	„
„ Runnpittiani	6	„
„ Loyach	8	„
„ Rhodh	3	„
Total	43	„

With regard to the Mulleer Viaduct, the most extensive of this class, the Author would merely observe, that the foundations and general construction were of an interesting character, on which he abstains from enlarging, as he finds that Mr. J. E. Hartley, (M. Inst. C.E.,) who was the Resident Engineer during its construction, is engaged in writing a special Paper upon it. From the experience acquired by the Author from these examples of Warren's girders, he is compelled to report unfavourably of them, when contrasted with plate girders. There is an amount of vibration, both laterally and vertically, caused by passing trains, which had the effect of breaking, or of loosening the bolts fixing the longitudinal timber stringers to the cross girders. To such an extent did this occur, that it was found necessary to appoint one, two, or three native workmen at each viaduct, according to its length, whose duty it was to inspect and repair these breakages, or loosenings, after the passage of each train. The cost of this was so serious, that it was found advisable to take up the original rails, and although it raised the line and interfered slightly with the gradients, to lay the ordinary permanent way upon transverse sleepers. This has had the effect of diminishing the evil, but not of removing it entirely. The arrangement of the timber platform over these viaducts the Author considers highly objectionable, inasmuch as, while loading the bridges, it adds nothing to the lateral stiffness, nor does it distribute the load over the whole area, as might have been the case. It is submitted that two layers of planking, each 3½ inches thick, laid diagonally, and crossed, upon which the ordinary permanent way could have been laid, would have been a better arrangement,—stiffening the bridge laterally, and distributing the load more uniformly. The sliding blocks upon which each girder is laid, for the purpose of meeting the effects of contraction and expansion caused by changes of temperature, were not found to work well. In several cases the large ashlar stones upon which the bed plates were fixed, were drawn out of their places, before the blocks would slide. It is considered that the roller system, as originally specified, would have been a better arrangement. The impossibility of getting at all the surfaces of the ironwork, to scrape and repaint them, is likewise a serious objection; for while there is no great amount of rain annually in Scinde, there are heavy dews for months together, which cause a rapid oxidisation of unprotected wrought iron. The large viaduct across the Chinnee Creek, of ten spans, each of 100 feet, for a double line, has not yet been erected, but the ironwork is already complete, and delivered at Kurrachee. The girders are of plate iron, of elliptic form in elevation.

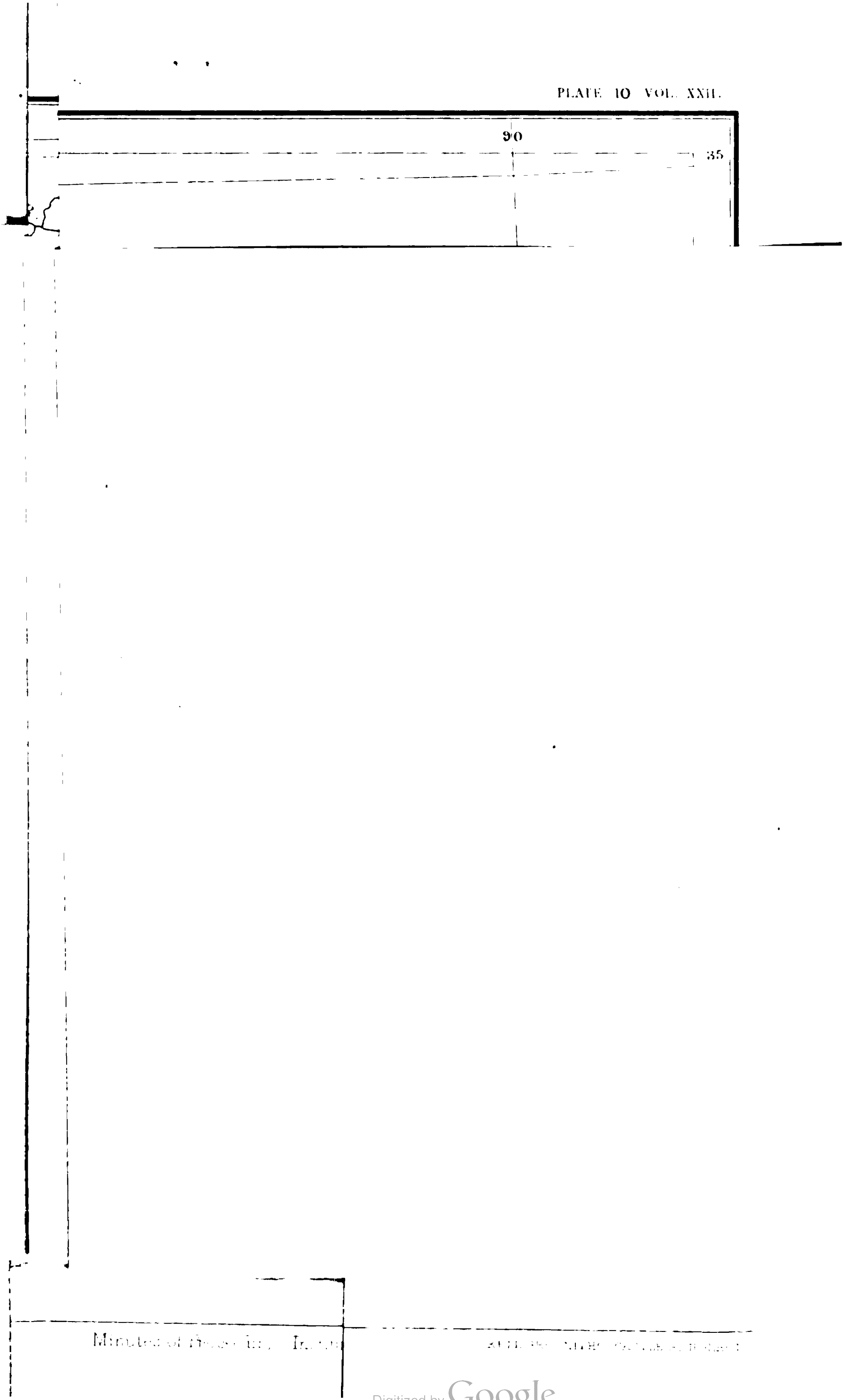
The majority of the works of the Scinde Railway were executed departmentally, as it is termed, or by the Company's own staff, without the intervention of a large Contractor. This mode of carrying on the works was forced upon the Company by the peculiar exigencies of the case. The merits of the rival systems have frequently been the subject of discussion, but the experience of the Author leads him to the conclusion, that for the execution of large works in India, under Government guarantee, the employment of a substantial Contractor is the best mode. The departmental system allows of an amount of Government interference in every petty detail which cannot exist under the contract system. As long as the works are pushed forward in accordance with the terms of the agreement with the Company, the Contractor is untrammelled, and he can act on his own discretion in the mode of carrying on his operations, without being involved in the interminable correspondence and delays which are inevitable under the departmental system.

The railway system, which thirty years ago was in its infancy, and struggling into public notice, has now arrived at gigantic proportions, and has not only spread its network over the land of its birth, but is extending, with rapid strides, over the vast continents of the world. During the early years of railway constructions, and while the works connected with them lay in civilised countries, the professional Engineer was surrounded by all the appliances of modern science, and had the command of skilled and unskilled labour, which rendered his duties comparatively easy. But the extension of railway communications into wild and uncivilised countries, demands from the Engineers, Agents, and Contractors engaged, the exercise of more than ordinary observation, self-discipline, and energy. This remark applies to all grades of the employés of a foreign Railway Company, from the Chief Engineer and Agent, to the lowest European Inspector. Each European employé almost necessarily occupies an isolated position as regards his fellow-countrymen. He is surrounded by natives, with whose language and habits he is but imperfectly acquainted. Yet upon the obtaining and securing the services and good-will of these natives, the progress and success of the work intrusted to his charge wholly depend. Great tact and temper are, therefore, absolutely necessary. It is flattering to know, that the natives of India place unbounded faith in the truthfulness and justice of a Briton, and when this high position is not weakened, or lost, by the improper acts of the individual, it is a most powerful instrument for good. Kind, considerate, just,. and withal firm treatment secures willing service; while an opposite course is followed not by retaliation, perhaps not even by remonstrance, but by the native quietly moving off in search of more humane treatment elsewhere. In carrying out the works of the Scinde Railway there was no lack of examples confirming the above opinion, as to the effect of the European's general treatment of the natives, upon the number and character of those whom he could attract to the works. Again, the Engineer or Inspector situated as above described, at a distance from head-quarters, meets with cases of emergency, when fertility of resource and self-reliance are most invaluable qualities; while at all times, and wherever he may be placed, energy of character and perseverance, combined with temperance, will alone render him a valuable officer. It becomes then the wise policy of all foreign Railway Companies, and of all Contractors for their works, to exercise the greatest strictness, in ascertaining that the agents sent out from this country at immense cost, are not only proficient in the practical details of their profession, but that they are also possessed of gentlemanly feelings and habits, which alone will command the respect of the uncivilised native, attracting him to the work, reducing its cost, and converting the Railway Engineer into a pioneer of civilisation and a missionary of science.

The Author has pleasure in acknowledging, that he is greatly indebted to the following gentlemen, members of the Engineering staff of the Scinde Railway, for much valuable assistance in collecting and recording the data from which the cost of the various works given in this Paper is calculated:—Mr. W. T. Warren, Mr. Henry Stone, Mr. Thomas Warren, Mr. J. E. Hartley, and Mr. J. Pinder.

The Paper is illustrated by a plan and section of the line, and by a chart of Kurrachee Harbour, from which Plates 11 and 12 have been compiled, as well as by an elevation, plan, and sections of the Bahrun Viaduct, and details of the mode of forming the masonry piers for the iron girder viaducts.

PLATE 10 VOL. XXII.



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APPENDIX.

BAHRUN VIADUCT.

COST OF EXCAVATING FOUNDATIONS, IN LOOSE SAND, DEPTHS AVERAGING 20 FEET.

Those parts which were let by contract, cost from 12 annas to 1 rupee 4 annas per 100 cubic feet, or per cubic yard 4·36 annas. Those done by day work, (after keeping a strict account for many months,) were found to cost:

	A.	R.	A.
One muccadum	at 6	0	6
Nine coolies	at 4	2	4
	Rs.	2	10

For this sum 8⅛ cubic yards were excavated, thus costing:

	ANNAS	R.	A.	P.
Per cubic yard	5·14			
About an equal number were excavated by the two modes, therefore add as above	4·36			
	9·50			
which, divided by 2, gives as the average cost per cubic yard		0	4	9
Add for tools		0	0	5
Average cost of excavation, or 9¼*d.* per cubic yard		0	5	2

COST OF CONCRETE.

	R.	A.	P.	R.	A.	P.
Lime per maund of 80 lbs.				0	3	2
Sand per 100 cubic feet				0	12	0
Stone per 100 cubic feet:						
Quarrying	1	0	0			
Breaking	1	0	0			
Hauling	2	12	0			
				4	12	0
Water per 100 cubic feet				1	4	8

For 100 *Cubic Feet of Concrete.*

	R.	A.	P.		R.	A.	P.	R.	A.	P.
Lime 17 cubic feet, at	0	3	2	per maund	0	14	2			
Stone 33 „ „	4	12	0	per 100 cubic feet	1	9	4			
Sand 50 „ „	0	12	0	„ „	0	6	0			
Water					1	4	8			
Mixing and depositing in place					2	12	0			
Total					6	14	2			
Or, per cubic yard								1	14	0
Add for tools								0	2	6
Total								2	0	6

Or, 4*s*. 0¾*d*. per cubic yard.

Cost of Ashlar Masonry, per 100 Cubic Feet.

	R.	A.	P.	R.	A.	P.
Quarrying	7	4	0			
Earthwork in baring quarry	1	0	0			
Dressing	30	0	0			
Water for men	0	8	0			
Maistry	0	8	0			
Smithwork—labour	1	3	0			
				40	7	0
Haulage	3	0	0			
Setting	12	0	0			
Water for mortar	0	12	0			
Lime	1	0	0			
Sand	0	4	0			
Maistry	0	6	0			
Tools and contingencies	4	11	0			
				22	1	0
Total				Rs. 62	8	0

Or, 1*s*. 3*d*. per cubic foot.

Block in Course, (Arches,) per 100 Cubic Feet.

	R.	A.	P.			
Quarrying	6	4	0			
Dressing	25	0	0			
Earthwork in baring quarry	2	0	0			
Water for men	0	11	0			
Smithwork—labour	0	10	0			
Maistry	0	10	0			
				35	3	0
Haulage	3	0	0			
Setting	11	8	0			
Water for mortar	0	14	0			
Sand	0	8	0			
Lime	1	8	0			
Maistry	1	0	0			
Tools, coal, templates, &c.	4	3	0			
				22	9	0
Total				Rs. 57	12	0

Or, £1. 11*s*. 6*d*. per cubic yard.

COURSED RUBBLE, PER 100 CUBIC FEET.

	R.	A.	P.	R.	A.	P.
Quarrying	6	0	3			
Earthwork in baring quarry	1	0	0			
Dressing	12	8	0			
Water for men	0	6	0			
Maistry	0	8	0			
Smithwork—labour	0	8	0			
				20	14	3
Haulage	2	4	0			
Setting	10	8	0			
Water for mortar	0	14	0			
Lime	1	8	0			
Sand	0	8	0			
Maistry	0	4	0			
				15	14	0
Total				Rs. 36	12	3

Or, £1. 0*s*. 0¾*d*. nearly, per cubic yard.

COMMON RUBBLE, PER 100 CUBIC FEET.

	R.	A.	P.	R.	A.	P.
Quarrying	3	6	0			
Smithwork—labour	0	8	0			
Water for men	0	6	0			
				4	4	0
Haulage	2	2	0			
Setting	10	0	0			
Lime	1	12	0			
Sand	0	8	0			
Maistry	0	8	0			
Water for mortar	0	14	0			
Tools and contingencies	1	10	6			
				17	6	6
Total				Rs. 21	10	6

Or 11*s*. 9¾*d*. per cubic yard.

CENTERING.

Deodar timber in one set of centres 1,910 cubic feet.
Iron in one set of centres 36 cwt.

	R.	A.	P.
Timber, 1,910 cubic feet, at 1 rupee	1,910	0	0
Iron, 36 cwt., at 12 rupees	432	0	0
Carpenters' work	140	0	0
Smiths' work	120	0	0
Nails, 112 lbs., at 3 annas	21	0	0
Total for one centre	Rs. 2,623	0	0

	R.	A.	P.
Cost of the 12 sets was, therefore	31,476	0	0
Fixing and removing in 32 arches	1,920	0	0
Total	Rs. 33,396	0	0
The timber of these centres was cut to a scantling which made it available for sleepers on the completion of the arching, and it was valued at	18,336	0	0

Further, the centres of the Bahrun Viaduct were made use of at the Koonee and Hurroola Bridges, so that the apportionment of the total cost of centering is as follows:—

	R.	A.	P.
Bahrun Viaduct 32 arches	13,386	10	8
Huroola Bridge 3 „	1,255	0	0
Koonee Bridge 1 „	418	5	4
Total . . . Rs.	15,060	0	0

Total Cost of the Bahrun Viaduct.

Amount paid to Messrs. Bray for work performed, up to the period of taking over the contract	40,412	0	0
Amount subsequently paid in the departmental execution of the works, exclusive of the higher classes of superintendence	206,944	6	4
Amounts chargeable under the head of plant, including trollies, crabs, chains, ropes, poles, scaffolding, &c.	24,500	0	0
Total . . Rs.	271,856	6	4
Or in English money . . .	£27,185	12*s.*	10*d.*

COST OF MASONRY AT KURRACHEE.

The following is a statement of the prime cost of masonry in the neighbourhood of Kurrachee, exclusive of European superintendence and working plant:—

Ashlar.

	R.	A.	P.
Two good men will prepare 8 cubic feet per day for 20 annas × 12½, or for 100 cubic feet	15	10	0
Two good men will set in general work 20 cubic feet per day for 20 annas, making for 100 cubic feet	6	4	0
To labour, including coolies', nowgunnies', smiths', and maistrys' pay	15	4	0
Cost of contractor's part . . Rs.	37	2	0
Add for quarrying stone, exclusive of powder, &c., for 100 cubic feet	4	0	0
Ditto for delivery of stone, if 5 miles lead, and supposing each cart to contain 7 cubic feet, at 12 annas per cart load, or for 100 cubic feet.	10	11	5
Ditto for lime delivered on the works	2	12	0
Ditto for sand „ „ „	1	4	0
Ditto for water „ „ „	0	12	0
Total for 100 cubic feet . . . . Rs.	56	9	5

£1. 10*s.* 6¾*d.* per yard,
Or about 1*s.* 4¼*d.* per cubic foot.

Block in Course.

Two good men will prepare 12 cubic feet per day, at 10 annas per day for each man, making for 100 cubic feet	10	6	8
Two good men will set in general work 20 cubic feet per day, at 10 annas each man per day, or for 100 cubic feet.	6	4	0
To labour, including coolies', nowgunnies', smiths', bullocks', and maistrys' pay	10	8	0
Cost of contractor's part . . . Rs.	27	2	8

	R.	A.	P.
Brought forward	27	2	8
Add for stone in quarry, exclusive of powder, &c., per 100 cubic feet	4	0	0
Ditto for delivery of stone, if 5 miles lead, and supposing each cart to contain 7 cubic feet, at 12 annas per cart load, per 100 cubic feet	10	11	5
Ditto for sand per ditto	1	8	0
Ditto for water per ditto	0	14	0
Ditto for lime delivered upon the work per ditto	3	0	0
Total for 100 cubic feet	Rs. 47	4	1

Or £1. 5*s.* 6¼*d.* per yard.

Coursed Rubble.

Two good men will prepare 20 cubic feet per day, at 10 annas per day for each man, making for 100 cubic feet	6	4	0
Two good men will set in general work 30 cubic feet per day, at 10 annas each man per day, making for 100 cubic feet	4	2	8
To labour, including coolies', nowgunnies', smiths', bullocks', and maistrys' pay	10	8	0
Cost of contractor's part	Rs. 20	14	8
Add for stone in quarry, exclusive of powder, &c., per 100 cubic feet	3	8	0
Ditto for delivery of stone, if 5 miles lead, and supposing each cart to contain 7 cubic feet, at 12 annas per cart load, per 100 cubic feet	10	11	5
Ditto for sand per ditto	1	8	0
Ditto for water per ditto	0	14	0
Ditto for lime delivered upon the work per ditto	2	12	0
Total for 100 cubic feet	Rs. 40	4	1

Or £1. 1*s.* 8¼*d.* per yard.

A Superior Class of Rubble.

Two good men will prepare and set 40 cubic feet per day, at 10 annas per day for each man, making for 100 cubic feet	3	2	0
To labour, including coolies', nowgunnies', smiths', bullocks', and maistrys' pay	8	0	0
Cost of contractor's part	11	2	0
Add for stone in quarry, exclusive of powder, &c., per 100 cubic feet	3	8	0
Ditto for delivery of stone, if 5 miles lead, and supposing each cart to contain 7 cubic feet per 100 cubic feet	10	11	5
Ditto for sand per ditto	1	10	0
Ditto for water per ditto	1	0	0
Ditto for lime delivered upon the work, per ditto	3	0	0
Total for 100 cubic feet	Rs. 30	15	5

Or 16*s.* 8*d.* per yard.

[Mr. W. P. Andrew,

Mr. W. P. ANDREW,—Chairman of the Scinde Railway Company—observed, that on the map of India, (Plate 10,)[1] this railway appeared to be a very small undertaking; yet in actual length it would be found to compare advantageously with some of the leading railways in England. For instance, it was about the same length, 108 miles, as the Great Western, from London to Bath, and very nearly equal to that of the London and Birmingham Railway, which was 113 miles, while the Scinde Railway was more than twice the length of the London and Brighton line. It was not, however, from its dimensions, but from its relation to other parts of India, that this line derived its great national and commercial importance. The immediate object for its construction was to meet the two great difficulties of the Indus, the creek navigation and the ocean swell of the open sea. All the serious accidents that had been attended with loss had occurred, either in the short navigation of the open sea, or in the creeks of the delta. By the last mail he had received a letter, stating that another company, (not in connection with the Scinde,) which proposed to establish a through navigation between the Punjaub and Kurrachee, had had three of their vessels seriously injured, the back of one being reported to have been broken, in the creek navigation. So alive had the natives been to the advantages gained by the Scinde Railway, and so much did they appreciate the regularity and certainty of railway communication, that the native craft which was formerly in the habit of coming to Khettie in the delta, as the port of trans-shipment, both for Bombay and Kurrachee, did not now come below Kotree, where the goods were trans-shipped and conveyed by railway to Kurrachee. In a letter received that day, it was stated that there was a length of two miles of native boats collected at Kotree, the upper terminus—which in itself was sufficient evidence to show the dangers of the sea and creek navigation by steamers and by native country craft, and to demonstrate the necessity for such a work as the Scinde Railway. The Agent of the Company further stated, that not a single native boat had gone below Kotree for the last two months. The immediate object contemplated by the Scinde Railway,—to relieve the commerce of the country from its two great dangers,—had thus been accomplished by substituting a railway of 108 miles, for the creek navigation of 230 miles. Moreover in a political and military point of view, it was of the greatest importance to be able to move troops from Kurrachee to Kotree in a few hours, instead of losing a week in conveying them up the creeks.

Looking at the map of Upper India (Plate 10), towards the north, a branch line would be observed on the right bank of the River Indus. That was the proposed line from Sukkur, viâ Shikarpoor and Jacobabad, to the Bolan Pass; the surveys had been partially executed, and it was found that the line could be easily and cheaply constructed. Its political importance was great; and a large portion of the traffic of Central Asia came down that Pass on its way to Kurrachee, and was subject to great difficulties and delays. Higher up was Moultan, the lower terminus of the Punjaub Railway: that line extended to Lahore and Umritsir, and from thence proceeded the Delhi Railway, which would form a junction with the East Indian Railway at Delhi. The traffic between Moultan and Kotree was now most imperfectly carried on by means of a large fleet of steamers, which he trusted would speedily be superseded by a railway. India would then have one of the longest continuous lines in the world, from Kurrachee to Calcutta, a distance of upwards of 2,200 miles, forming a great steam arch connecting the Arabian Sea with the Bay of Bengal. This would give the greatest protection to the empire of India, by affording the most effectual means of quelling disturbances, either within or without the frontier. It would, moreover, powerfully develop the enormous resources of the interior of the country, bringing to the port of shipment that produce of its plains which was so urgently required in England. The capabilities of India were but little understood. The discrepancies of conflicting authorities might, however, be accounted for when it was considered, that India was a country of vast extent, being as large as the whole of Europe without Russia, that it possessed every variety of soil and climate, and that, from the different elevations of the plateau, its products necessarily varied.

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[1] The scales of English miles and of geographical miles attached to this map are inaccurate. The figures should be 0, 25, 50, 100, and 250, instead of 0, 50, 100, 200, and 500.—ED.

With regard to the cost of the Scinde Railway, he thought that it would slightly exceed the average cost of railways in India, which he believed to be about £15,000 per mile. But there were peculiarities in the case of the Scinde Railway which would, in a great measure, account for this excess. In the first place, there was considerable difficulty in procuring from England freight for the materials, for at the time the concession was granted, Kurrachee was scarcely known, and it became necessary to investigate and to publish the capabilities of the port. In the second place, the Scinde Railway comprised, in proportion to its length, a more than usually large number of such works, as piers, wharves, &c., which did not ordinarily belong to railways. Then there were difficulties when the materials arrived in India; the Company having even to provide their own boats for unloading the vessels, and as there was a deficiency of labour, labourers had to be imported from Cutch and Central Asia, and from the confines of China and Persia. All these obstacles were overcome, however, by the energy and perseverance of the Author of the Paper, and the Engineering staff under him, and Sir Bartle Frere, the then Commissioner in Scinde, and the present Governor of Bombay, had borne testimony to the admirable manner in which the affairs of the Company were conducted.

There was one important engineering point on which it was desirable to elicit an opinion,—that was the best material for sleepers in India. In Scinde the soil was hard and stony; many of the cuttings were through rock, and the embankments consisted, in great part, of stone. The kind of sleeper which would answer there would probably be ill adapted for the railways in the Punjaub. On the Scinde line, the sleepers had been prepared in a variety of ways, but they had all apparently retained their original size and form, thus presenting, as he understood, a great contrast to the wooden sleepers employed in almost every other part of India. On those lines, the sleepers had, irrespective of the attacks of the white ant and notwithstanding every precaution, become desiccated and had almost entirely disappeared, from the effect of natural decay. From his own acquaintance with India and with the habits of the white ant, in 1846, he had ventured to predict that the apprehension of the ravages of that insect upon railway sleepers was exaggerated. The results had proved as he had predicted, that whatever was liable to sudden concussion, or vibration, would never be much affected by the ant, as it always worked under a covered way, and whenever that covered way was disturbed, it invariably retired. As in the Punjaub there was a great difficulty in procuring wooden sleepers, the Company had, upon the recommendation of Mr. Bidder, (Past-President Inst. C.E.,) sent out several miles of iron sleepers. As they were only being now put down, it was impossible at present to give an opinion as to their adaptability.

He desired also to call attention to another engineering point connected with the Scinde Railway, which was perfectly novel to him. From some cause or other, the waterway appeared to be insufficient to allow the drainage of the country to pass beneath the line, and the Engineer had adopted the expedient of allowing, on a part of the line, the water to flow over, instead of under it. The water appeared to glide over slowly, and the ballast being heavy stone, the line was not injured, nor had the traffic been interrupted by this peculiar mode of treatment.

From the days of Sir Henry Pottinger[1] and Sir Charles Napier[2] to the present time, the attention of Indian statesmen had been directed to the political and strategic, as well as to the commercial importance of Kurrachee. A good port capable of admitting at all hours and seasons ships of large burden, was indispensable to the success of the combined system of rail and river for the valley of the Indus, intended to be carried out by the Scinde and the Punjaub

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[1] *Vide* Letter from Sir H. Pottinger to Mr. W. P. Andrew, in "The Scinde Railway, and its Relations to the Euphrates Valley and other Routes to India." London, 1856.

[2] *Vide* "The Indus and its Provinces." By W. P. Andrew. London, 1857.

Railways, in conjunction with the Indus Flotilla. Such was to be found in Kurrachee, the most western port of India, and the only land-locked harbour between Bombay and the Persian Gulf. It was perfectly safe and easy of access for large ships, by day and night, and even during the monsoons. According to Commodore Young of the Indian Navy,[1]—who, as far back as 1854, took the steam frigate 'Queen' twice into Kurrachee in the night time, during the south-west monsoon,—it, though a bar harbour, had sufficient depth of water, even in its existing state, for ships of from 17 feet to 18 feet draught, at high water of ordinary tides. At high spring-tides, the depth was from 20 feet to 21 feet, and at times, even 22½ feet. In this view, Commodore Young was confirmed by Commodore Rennie,[2] of the Indian Navy, who, during the preparations for the late expedition to the Persian Gulf, was constantly in and out of the harbour with troops, and became convinced, that there was frequently more water on the bar than was shown by the port register. As a proof of this, the 'Bussorah Merchant,' a large vessel drawing 20½ feet of water, passed the bar when the register showed 21 feet. To that able and excellent officer, Captain C. D. Campbell, I.N., belonged the credit of having been the first to take, on his own responsibility, a large armed steamer into the harbour of Kurrachee.

From the Ganges to the Oxus, whoever wished to communicate with any place beyond the sea, must pass through Kurrachee, which thus occupied a position scarcely less favourable to commerce than Alexandria. The port was protected from the sea and from bad weather, by Manora Point, a bluff rocky headland projecting south-eastward from the mainland, and leaving a space of about 2 miles between the extreme point and the coast to the east. The harbour was spacious, extending about 5 miles northward from Manora Point, and about the same distance from the town, on the eastern shore, to the extreme western point.

To be the nearest point to Europe of all the British possessions in India was important in many respects, but more especially with reference to the Euphrates Valley route; and every remark relative to the direct communication of Kurrachee with Suez was equally, if not more, applicable to that with Bussorah, as materially reducing the sea voyage from India. When the proposed telegraphic communication should be established with Europe, whether by the Persian Gulf, as advocated by him, or the Red Sea, or, as it ought to be, by both routes, the advantage would be great, of being the medium of disseminating the political and commercial intelligence of Europe to the most distant parts of India, and giving in exchange the most recent events there, and also in Central Asia. Until lately beyond the pale of the electric chain, which already spanned the eastern empire, Kurrachee was destined, ere long, to become the chief seat of the telegraph in India, and from its geographical position, it must become the European port of India. It was (Plate 13) 205 miles nearer than Bombay to Aden; and for three months in the year, during the prevalence of the south-west monsoon, it was virtually 735 miles nearer.

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[1] *Vide* "The Indus and its Provinces." By W. P. Andrew. London, 1857.

[2] *Vide Ibid.*

Nearly ten years ago, Sir Bartle Frere, the present Governor of Bombay, remarked,[1] "it might be premature to dwell on the certainty of this port (Kurrachee) becoming, ere long, the channel of a direct steam communication with Aden. But compare the length of the run hither from Aden with the length of the run to Bombay; and consider that the passage from Bombay to Aden is, for three months in the year, in the teeth of the south-west monsoon; that on the line from this to Aden, the south-west monsoon does not blow with violence, and is, in fact, not more than a steady trade-wind, equally favourable for the run to, or from Aden, the result of a consideration of these circumstances can hardly be other than a conviction, that a direct steam communication will be established at no distant period, and from the large number of passengers between the Punjaub and England, to whom it is of importance to avoid the delays and expenses of going round by Bombay, there can be little doubt but that it would prove a good passenger line."

Mention was made in the Paper of the extensive works carried on by Government for the improvement of the harbour. Mr. Andrew could further state, that the Scinde Railway Company had sent out from England more than one hundred ships, and that no accident had occurred to any of them either in entering, or on leaving the port.

Mr. **Bruce** said, it appeared from the statement of the Chairman of the Scinde Railway, that the cost of the line might be estimated at rather more than £15,000 per mile, and the average prices of the different descriptions of work were given in the Paper; but there was another necessary element in the consideration of the case, the price of labour, by which alone it was possible to judge whether the work was cheap, or dear. The price of earthwork was stated to be 11½*d.* per cubic yard, and that of block in course 31*s.* 6*d.* per cubic yard. Now he hoped he should not be considered as stepping beyond proper criticism in saying, that he thought those prices were too high, under almost any ordinary circumstances. The cost of the line was, in his opinion, much too high for a poor country,—for although India was extensive, still the people were poor,—and if railways were to be widely extended in that country, some means must be found of making them at a cheaper rate. He thought it probable, that those railways which had been the pioneers, had borne the brunt, and that it would be found possible now to introduce a better system, by which future lines could be laid down at less cost.

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[1] *Vide* "The Scinde Railway, and its Relations to the Euphrates Valley and other Routes to India." By W. P. Andrew. London, 1856.

The Author had alluded to the difficulties in which he was placed, by the Contractor not being able to carry out his engagements, he being in consequence, compelled, to undertake the management, and to conduct the works himself. The question whether works should be carried out through the medium of Contractors, or not, had often been mooted at the Institution. Although Mr. Bruce himself had set an opposite example, in dispensing with a Contractor in India, he quite agreed with the Author, that the proper system, which should not be deviated from without good reason, was to let the work to a large Contractor, capable of thoroughly executing it, and thus to relieve the Engineer, to a great extent, of the burden of detail. There was nothing like division of labour when properly carried out, and where it was possible to submit work to a fair amount of competition, so as to secure fair prices for the Company.

There were some points of a general character in the Paper, which he thought called for remark. The Author stated, that the price of labour was fixed by the magistrate. Mr. Bruce's experience in such matters was, that the less recourse was had to the magistrate the better, and that the Engineer should fix the prices for everything. The magistrates had too much power, and though they exercised it efficiently in their own work, still it was a mistake to require of them more than to render the protection ordinarily and everywhere expected from magistrates. The Author had followed a system, which was very wise, that of endeavouring to train young people in India for the different trades, but the pay allowed them appeared to be high. From £3 to £8 per month was large pay for a youth learning his business. As to the sleepers, the Author stated that a large proportion of those which had been sent from this country were of creosoted red and white pine, and that they had generally failed. Mr. Bruce had been in the habit of sending out red pine, but as a general rule, he preferred using cast-iron sleepers in India; and he had no doubt it would be found, that those sent out upon Mr. Bidder's recommendation would be efficient and last well. It was, however, quite certain, that if wooden sleepers were sent out, they must be of the best kinds of wood; it was useless to trust to creosote for making good the deficiencies of the timber itself.

With regard to the question of water-way, he thought it would have been a better, a surer, and in the end, a more efficient and economical course, to have provided proper openings for carrying the water under, or through, than to allow it to run over the railway. Although there might be circumstances in this particular case of which he was not fully aware, which might justify the course adopted by the Author, he thought it was not a desirable system, or one which it would be safe to follow to any extent.

Mr. Bruce cordially agreed with the remark at the end of the Paper, as to the necessity of taking care to send to a foreign country, men who were not only good mechanics, but also of good character. The main element for consideration in the men to be sent out, of whatever grade, should be character, because the natives looked up so much to Europeans, that if they were not men of steadiness and honesty, they obtained very little power, or control in India. That was a point which could not be too much insisted on in carrying out works of this description, in countries far removed from head-quarters.

Mr. G. BERKLEY remarked, that in a Paper submitted to the Institution in 1860, by his Brother, (the late Mr. James Berkley,) it was stated, that the prices paid in Western India for block in course, varied from 16*s*. to £1. 15*s*. per yard.[1] It was, therefore, evident that circumstances varied considerably, and that it was extremely difficult to fix upon any average by which to compare prices in two districts, where the conditions might be entirely different. In the same Paper, the price of earthwork was stated to be much lower than in the present case; but it should be remembered, that the lead was only a quarter of a mile, whereas on the Scinde Railway it might have been longer, and thus the prices might be a fair representation of the circumstances under which the Author had been working.

He would refer to the subject of the improvement of the port of Kurrachee, merely with the view of drawing attention to what appeared to be one of the most important objects in these undertakings,—the means adopted for loading and shipping goods at the termini of the various railways. On the Scinde Railway the appreciation of its importance was demonstrated by the early consideration it met with, and by the execution of efficient works at the seaboard terminus. At Bombay there was a first-rate harbour, and although, for many years past, several plans had been suggested, he had not yet heard of any practical step having been taken towards effecting the improvement so much required. Station accommodation at the Bombay Terminus of the Great Indian Peninsula Railway was also a subject the consideration of which had occupied much time.

With regard to creosoted sleepers, he had found them liable to split when they arrived in India, and there was also an objection to them as cargo, on account of their inflammability and their liability to injure other goods. The same objection applied to carrying creosote itself.

He agreed with the remarks, as to the importance of sending out agents and work-people of good character: this was, however, a matter of considerable difficulty. The great desideratum was to find old heads on young shoulders; men prompt and practical, and at the same time, of tact and temper. The Engineers and others who had gone to India had, as a body, very creditably represented their countrymen; but it would be extreme good fortune always to obtain men with these remarkable characteristics combined.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xix., p. 609.

Mr. W. A. Brooks observed, that Kurrachee was, with the exception of Bombay, the only good harbour on the western coast of Hindostan. With reference to the statement in the Paper, that an improvement had taken place in the depth over the bar at Kurrachee since the Keamaree Pier had been carried out, it appeared from the chart, (Plate 11,) that the greatest available depth was only 15 feet, at low water of spring tides—a depth which did not warrant the statement that any improvement had taken place; because the survey made in 1848-49 by Mr. Fenner, a master in the Indian Navy, and marine surveyor, gave the same depth, (15 feet,) which added to the 9 feet rise of tide, made 24 feet, as shown on the chart. In 1853 it was recorded, that the high water depth was 23 feet. In 1856, the late Mr. Walker reported, that at low water of spring tides the depth was from 9 feet to 12 feet; but in a Paper of Directions for approaching Kurrachee, dated January, 1860, the depth on the bar at high water of spring tides was stated to be, S.W. monsoon, between May and September, from 22 feet to 23½ feet.[1]

It was important to recollect, that at present the harbour of Kurrachee was almost a pure tidal receptacle, and that, therefore, any works which diminished that receptacle for the tide must have the effect of greatly injuring the harbour. Formerly, a large volume of the floods of the Indus passed into the harbour by the Lyaree Channel, but little came down now. He was desirous of directing the attention of the meeting to the contraction of the tidal flow presented by the works projected by the late Mr. Walker, and now in progress; because there was, in his opinion, great danger that a noble harbour might be ruined. It was part of Mr. Walker's design to extend from Manora Point, a pier, on the eastern side of which, a shoal would most certainly be deposited, precisely similar to that now existing on the eastern side of the point. The construction of the pier, as proposed, must be followed by a proportionate extension of sand under the lee side, during the prevailing set of the current along the coast; the bar would be merely shifted a little farther out, and would overlap the Keamaree Pier, just as the bank, in its natural condition, overlapped it at present. This would always render it difficult for ships to enter the harbour when the wind was from the westward. It must be evident, that vessels trying to weather Keamaree Pier head, would be in constant danger either of falling upon it, or of being driven to leeward of the harbour.

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[1] *Vide* "The Engineer's Journal," July 1, 1861. Vol. iv., p. 132. Calcutta, 1861.

In the 'Calcutta Engineers' Journal' for July and October 1861,[1] there appeared an able Paper on Kurrachee Harbour, by Lieutenant A. D. Taylor of the Hydrographical Department of the Indian Navy, in which he recommended a pier to be made from the shore at Clifton, and, after passing over the Oyster Rocks, to terminate abreast of Manora Point, leaving a capacious entrance between the pier head and the point. Mr. Brooks stated, that he had given much attention to this subject, and that he considered Lieutenant Taylor's plan to be better adapted to improve the mouth of Kurrachee Harbour, and to augment the tidal receptacle, than the present works. Moreover, if the eastern pier were made to extend rather beyond Manora Point, the set of the prevailing current would be against its inner, or harbour face, and would act beneficially in maintaining good water on the bar.

Mr. PARKES said, that he had made the survey of the harbour of Kurrachee, and had assisted the late Mr. Walker in the design, but the work was being carried out entirely under the Public Works Department of the Bombay Government. He would however mention one fact to show the incorrectness of Mr. Brooks's conclusions. At the end of Manora Point the water was about 9 feet deep, in which depth the waves broke. In breaking, they lifted the sand from this shallow bottom, and rolled it forward into the stiller water immediately under the lee of the point. If the pier were carried out, its extremity would stand in a depth of 24 feet, and the waves would not break. There would, therefore, be no tendency to lift the sand, and, consequently, no tendency to form a bar there. He had been informed, that the groyne, which he believed had lately been completed along the Keamaree Spit, on the opposite side to the entrance, had already produced considerable effect upon the bar. The bar was in a transition state at present, and, therefore, all he could now say was, that the sand had been considerably moved. The navigable channel being circuitous would not, in its existing position, be much affected by the increased scour, but the top of the bar had been lowered to a great extent, and when the increased scour caused by the groyne had gone on a little longer, the bar would, no doubt, be reduced to a much greater extent, and a more direct and much deeper navigable channel would be formed. The immediate effect, though as yet incomplete, was very encouraging. Mr. Brooks had alluded to the importance of maintaining the tidal space within the harbour, but he had omitted to mention the fact, that by Mr. Walker's designs, probably about one-fifth would be added to the original area; the water covering the whole of the space to the eastward of the Napier Mole would be brought through the harbour, instead of escaping, as it now did, through Chinnee Creek. Mr. Parkes thought these few particulars might be interesting in connection with the sea terminus of the Scinde Railway, now under discussion, but he objected to having imported into it any abstract questions of the principles of harbour engineering, as applied to this particular case, to which the subject of the Paper was entirely foreign.

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[1] *Vide* "The Engineer's Journal," vol. iv., pp. 132 and 186. Calcutta, 1861.

Mr. **Brooks** observed, that he had not only offered an opinion, but he had also given the reasons upon which that opinion was based. Mr. Brooks desired to reply to the remarks relative to Kurrachee Harbour, but it was intimated that it was advisable to restrict the discussion to the Scinde Railway, which was the main subject of the paper.

Mr. G. P. **Bidder**, Past-President, said, his observations upon the engineering questions would be confined to a few points. With respect to the plan adopted for the passage of the flood water over the Scinde Railway, he quite concurred in the views of the Author, which he believed to be practically and commercially right. It was easy to say, that it would have been more perfect to have constructed archways for the passage of the flood water, but the question was, at what cost could it have been done, and at present, there was no information, there were no facts, upon which to determine the extent of archway required. The only fact before the Meeting was, that the floods to be provided for were exceptional and local; the Engineer would thus be in the dilemma, either of having to construct an amount of archway altogether unnecessary, or such an amount as would be insufficient, and the effect of the inundation would be occasionally to stop the railway. He believed the smallest estimate of the cost for the provision of such an extent of archway as would be required, was about £70,000; and this enormous expense would be incurred merely to obviate the chance of two, or three stoppages of the line, in the course of eight, or ten years. He thought, that on such a railway as the one under discussion, it was better to save the outlay of £70,000, and put up with the occasional stoppage of the line. Perfection might be obtained at too high a cost. As to sleepers, that was still a question to be solved for India. He had recommended cast-iron sleepers, on account of their success in other places. The Company were in a difficulty: the Contractors had failed to supply the wooden sleepers, and the employment of cast-iron sleepers was the only remedy that presented itself. Whether they would prove the best, or whether any other form of sleeper would be better, had still to be ascertained.

Mr. Brooks had raised an important and interesting question. Looking, on the one hand at the vast extent of India, and its prodigious population, and on the other, at the very few effective ports, and comparing it with Great Britain, with only a fifth of the population, but with ports on every part of the coast, the importance of the question was at once evident; in fact, he believed that no outlay, however large, would be misapplied which would tend towards perfecting the ports of India. Mr. Brooks had correctly stated, that the only two good ports were Bombay and Kurrachee; Madras was no port at all, and Calcutta was as bad as it could be; yet those were, at present, the only outlets for the vast trade of India.

The question to which he wished to direct attention was far more important than that of the engineering, or of the ports. It was as to the mode in which Indian railways were, in future, to be carried out and worked, and he believed that on that question would depend the future extension and success of railways in India. There was one great satisfaction in looking at the map of India, that the lines at present executed and in progress were in the right direction. The lines from Calcutta and Kurrachee, meeting at Delhi, with their eventual connection at Bombay, must be the permanent backbone of the railway system in that country; and if that system were completed, and if nothing more remained to be done, it would be unnecessary for him now to advert to the peculiar conditions which attached to the construction of Indian railways, and the difficulties under which they had been carried out. When the railways in India were projected, three financial systems were open for consideration. First, their being carried out by private enterprise; that broke down at once, because the capitalists of England were disinclined to take them up on their own account. Secondly, the method of subvention, which never was, he believed, seriously entertained. Thirdly, there was the system of guarantee, which had been ultimately adopted. Before further adverting to that system, he would remark, with a view to prevent misconstruction of what he was about to say, that he had no strictures to make upon the mode in which it had been administered, whatever imperfections might attach to the system itself. That it had been carried out with any degree of success was, he believed, greatly owing to the endeavours of all parties to make it work. Every one had gone, more or less, beyond strict routine, otherwise the railway system in India must long ago have collapsed. At present the railways in India were entirely carried out on a system, by which the Government guaranteed a certain rate of interest upon the outlay. The result was that the Government was liable for the interest on all the outlay, so that, in fact, they had to look to the receipts of the railways for the repayment of the liabilities thus incurred. The Government, therefore, felt it necessary to overlook the whole of this outlay, and for that purpose there was established a system of supervision, permeating into the greatest minutiæ. The consequence was, that all individual energy and all independent activity were restrained; and, as he said before, unless the authorities, particularly the official directors, so far as his experience went, had applied themselves very much to the oiling of the machinery, he thought it must very soon have stopped altogether. He trusted, therefore, that his remarks would be taken as applied to the system, and not to individuals, or to bodies of individuals, for he was bound to say that India was a field which brought out, in every respect, and in a most peculiar manner, the energies of the Anglo-Saxon race.

The whole political system of England, from the beginning of the establishment of her rule in India to the present time, had been, theoretically, the worst possible; and that glorious empire had been established by the individual energy of those who represented this country in India. This remark applied peculiarly to those who had been connected with the railways of India. The amount of work which the Directors, particularly the Chairmen, had gone through, was prodigious; the amount of correspondence was marvellous, and that they should have had the patience to drag through it, was, he was bound to say, perfectly astonishing. The question arose, whether it was desirable that the system should be changed, and whether so much yet remained to be done in India as to make it desirable that the reconsideration of the system of making and working railways in India should be seriously entertained. With regard to the extension of railways in India, the backbone of the system was still far from being completed; the line from Umritsir to Delhi, a length of 300 miles, remained yet to be accomplished. If the Indus had been a deep, quiet canal, the carrying of the railway system along that valley might for some years have been postponed; but the Indus was perhaps the worst specimen of inland navigation that could be conceived, and, as the Author had stated, the channels of navigation were 570 miles in length, as against 470 miles of direct route. Mr. Bidder had very carefully considered the question of the Indus Flotilla, and he was every day more satisfied, that the necessity of occupying the valley of the Indus with a railway was becoming more urgent. Even in regard, therefore, to that backbone, there were about a thousand miles of railway yet to be constructed. The question then arose as to the best mode in which it could be carried out, and the best system of working it, when completed.

He had already stated that the Government of India was liable for a given rate of interest upon the whole outlay for the railways; there was, therefore, a distinct interest in the receipts, and the same minute supervision was exercised in the working as in the construction of the lines. Before any comparatively unimportant step could be taken in the Punjaub, sanction had to be obtained from the Lieutenant-Governor of the Province, which he could not grant without reference to the Governor-General of India; and, in a similar way, the Commissioner of Scinde was powerless without the sanction of the Governor of Bombay. Then again requisitions for manufactured railway material and for workmen, sanctioned by the officials he had referred to, had to be reviewed, commented upon, and indorsed by the Secretary of State for India in Council in London, before the most urgent want could be supplied. As regarded the construction, he was satisfied that the necessary restrictions which the system imposed caused a waste of time to the extent of 25 per cent., and at least an equal waste of money. But in the working the results would, he believed, be far more serious. How was it possible to work a railway efficiently, economically, and energetically, to develop the traffic, and adequately to meet the ever-varying demands of the public for accommodation, when a new foreman could not be appointed, nor his salary be fixed, without the manager undertaking a large amount of correspondence, involving duplicates and references to perhaps two or more jurisdictions, and a necessary delay of months. Take such a case as the London and North-Western Railway, and he asked could such a system be worked at all, if a correspondence begun in England had to be concluded in Calcutta, and passed through the Government Departments, before practical effect could be given to it. These departments, he fully admitted, were most anxious to do what was right and proper,—desirous even to go out of their way to give facilities; but still that channel must be gone through, and the result of such a system, whatever its effects might be upon the original construction, would be felt, in his opinion, much more seriously afterwards in the management and in the traffic arrangements.

To return to what he considered the system ought to be, and on which he spoke with some decision, from the experience he had had of its satisfactory working in another quarter. First, with regard to the construction of the railways, he thought that the Government should receive tenders from companies of capitalists for the completion and equipment of a line of railway, for example, between two given points, for a definite sum of money, and stating the amount of subvention they required from the Government, to be paid in cash, or by an equivalent. The character of the line as regarded materials, workmanship, and accommodation, being defined, the maximum rates of fares, the regulations connected with the public service, such as conveyance of troops, &c., being fixed, the total capital, the amount of subvention, and the approval of the railway by the Government on the completion of the same, being provided and stipulated for, the construction and the working should be left entirely to the management of the Company, who should take, as a first charge upon the net revenue, interest upon their portion of the capital up to an agreed amount, say 5 per cent., and the surplus revenue afterwards to be divided in agreed proportions between them and the Government. By so doing, all the energy of independent management would be brought to bear, and that management would work with the same responsibility and limitation as in this country. He believed that, upon that system alone, the full advantages of railway communication in India, or in any other country, would be realised.

He would, for the sake of illustration, assume a case, that of a railway up the Indus Valley, 500 miles in length, and that the reasonable cost, including equipment, was £10,000 per mile, or that a capital of £5,000,000 would be required. Of this he would suppose the Government to furnish £5,000 per mile, or two and a half millions of capital, either in cash, or by an equivalent guarantee; and as the Company would have to find the balance, and to satisfy the Government that the bargain had been efficiently carried out, there would be every possible responsibility thrown upon the executive, that all the money would be economically and judiciously applied. Then the working, subject to conditions with the Government similar to those he had indicated, should be conducted entirely by the Company, who should rely upon the receipts of the railway alone for a per-centage upon their capital up to, say, 5 per cent.; and after that, the net receipts should be divided, say two-thirds to the Government and one-third to the Company, as an inducement to the latter still farther to develop the traffic, and to work economically. This arrangement of course implied a proper audit of accounts for the satisfaction of the Government. He believed that it would be to the advantage of Government to apply this system of working to railways already opened for traffic, and to those now under construction; for instance, the lines from Kurrachee to Delhi, a length of from 600 to 700 miles, exclusive of the Indus Valley. For the privilege of working these lines, Government might receive, by tender, a contribution from a Company of say three or three and a half millions sterling, which would be more than adequate for the subvention of the Indus Valley line, which if carried out would complete a system of 1,100 miles, or thereabouts, from Kurrachee to Delhi, with a preferential capital of about five and a half millions sterling, with a preferential interest of 5 per cent., and a further contingent advantage from surplus net receipts. He was certain that the Government would get more profit under that system than under the present one, of taking the whole of the profits to meet the liabilities they had incurred, and they would have that contribution to apply to the extensions which might be made to this great backbone of railways throughout India; because though it was a poor country, mile for mile, yet when it was considered that there was one mile of railway in England for every 3,000 inhabitants, as against one mile of railway in India for every 50,000 inhabitants, it would at once be seen that, in India, the necessity for branches and extensions would grow in importance every year.

Looking to the rapid rate of increase of the trade of India, exhibited by the growth of the traffic on the Scinde Railway, in the face of the greatest possible hindrances to the transit of goods from the interior, he had the strongest possible conviction, that the application of individual skill and energy would realise a fair return upon all the capital which might be contributed, either by Government or by private capitalists, and concurrently, incalculable advantages would result to the trade of India generally.

He did not think that it was necessary to enlarge his observations on this subject. He had pointed out what occurred to him as the rational system to adopt, a system which, he believed, might be made to work very practically. It was the system on which the Norwegian Trunk Railway was carried out. Parties in England contributed one-half the capital, and the Government the other half. The English contractors took 5 per cent. preference, and the Norwegian Government took 4 per cent., and the surplus was equally divided. That system had been carried out without any difficulty, or contention whatever. He did not mean to say that those exact terms would apply to India; but a system which admitted of independent energy, and obviated the .necessity of state interference in construction, and a restriction in all the arrangements by which alone railways could be effectually carried out, would, in his opinion, be found advantageous to that great empire, and economical to the Government.

Mr. J. BRUNTON, in reply, said an objection had been made, that the Paper did not contain a list of the prices of labour. Now it was expressly stated, that he abolished the day-work system almost entirely, and established a system of piece-work, because he was convinced that it was the only means by which he could get the work done at the lowest possible price. Had he given a list of the daily wages paid to the labourers, it would have led to erroneous conclusions, because some were paid 4 annas, and others 5 annas or 6 annas per day, and at those wages they did little, or no work. He did not think the prices of day-labour furnished so good a criterion as the price at which, for instance, a cubic yard of earthwork was excavated and carried a certain distance; it was the same with regard to masonry. With respect to the observations about the magistrates fixing the prices of labour, that was a misapprehension. The magistrates were only called upon to fix the prices at which the provision dealers should sell their flour and other articles for the consumption of the labourers on the works; they did not interfere in any way with the prices of labour. As to the amount of £3 per month paid to the apprentices for the first year, he had a great deal of correspondence in India upon that very subject, before those prices were fixed. He maintained it was absolutely necessary for the European boy in India, particularly if separated from his parents, or taken away from his guardians, that he should receive a pay that would enable him to keep himself independent of and superior to the natives. The amount of £3 per month would not, in India, be considered a high rate of pay to keep a youth of 15 or 16 years of age in a respectable position; and it was only respectable lads of good character that were admitted as apprentices in the Company's workshops. He was not surprised that £16,000 per mile should have been considered a high rate of cost. It would be so, undoubtedly, for a line of railway running through a very flat country, which was the character of the districts through which most of the lines of railway in India were carried; but a glance at the section of the line between Kurrachee and Kotree would convince any Engineer that it was not an easy one. There was a considerable amount of earthwork upon it; and the earthworks were not of the soft character usually found in alluvial plains. The majority of the excavations were through hard rock, requiring gunpowder; many of the embankments were formed from side cuttings in rock, as no softer material could be obtained, and the embankments were built up with the stone so quarried from the side cuttings. That, coupled with the fact that the line crossed the natural drainage of an extensive hilly district, and required large viaducts and many culverts and bridges, would account for the increased cost per mile. But, as the Chairman of the Company had remarked, the Scinde Railway might be considered as rather exceptional, because, for a short length, it had two expensive termini, and there had been a heavy charge upon the capital of the Company for wharves and other works for the accommodation of the flotilla at Kotree, where from 3,000 feet to 4,000 feet of wharves had been constructed.

Since the reading of the Paper, he had received a communication from General Goodwyn, of the Bengal Engineers, with regard to the Burnettising process of saturating sleepers with chloride of zinc. That gentleman had paid great attention to the subject in India, and had made the following report to the Government:—

"I have the honour to report, for the information of the Board, that I have this morning been engaged in the examination of the timbers, bamboos, and other articles that were subjected by me, in 1846, to immersion in chloride of zinc; the following is the result:—

"II. The hair and woollen articles from the arsenal appear to have been uninfluenced by the solution, and have rotted, whilst some portions of canvas have been attacked by white ants, though slightly. The greater part of the canvas is sound and untouched; the twine and small rope are sound and good; whilst all wooden articles have been entirely preserved—such as the handles of brushes, sieve rims, and fusees.

"III. The whole of the sál timbers of various scantlings are quite sound, free from rot, or white ant; whilst one piece that has been buried in a fungus pit five years is as sound as on the day it was put in. The bamboos, a perishable material, are sound and strong in every way.

"IV. These timbers had been indiscriminately piled up in an open shed, where white ants abound, and exposed to alternate heat and moisture, where other timber has been destroyed in less time.

"V. The deal Memel, and even oak timbers, that were received from England in the same year, saturated by Mr. ——'s process, have all been attacked by white ants, some completely eaten. They were stacked in the same way, and in a similar shed.

"VI. The solution that my timbers were soaked in was chloride of zinc; the process patented by Sir William Burnett. It was the refuse liquid from the galvanic batteries in use at the Mint for refining of silver.

"VII. Major Baker and Mr. Turnbull, the senior Engineer of the Railway Department, were with me, (in fact, it was to show them that I scrutinised the whole,) and they were satisfied of the efficacy of the process. I consider this to be so satisfactory, as to be worthy of communication to Government.

"I have, &c.

"*Fort William*, "(Signed) H. GOODWYN.
"*27th September*, 1852."

General Goodwyn further stated, in a letter received that day, that since the above report was written he had been confirmed in the opinions he had expressed. This was of great importance; for if the native timber could be preserved by so simple a process as that of immersion in chloride of zinc, more of the woods of India could be used in future for sleepers. Mr. Brunton's experience did not extend over a sufficient time to enable him to form a conclusive judgment upon its preservative qualities; but he had applied it on his own line to sleepers, and to cills and door-frames, and hitherto the timber so prepared had not been attacked by white ants.

With regard to the water-way, and the novel mode he had adopted of lowering the line of railway from the low embankment on to the surface of the country, and laying the rails flush with the surface, he observed that he had done this almost from necessity; for the only alternative was the very expensive one of constructing a continuous series of culverts over the whole distance. Then it was to be remarked, that the rains in Scinde were different from the rains in other parts of India; Scinde, in that respect, must not be judged by the lower parts of Bengal, or Bombay. In Scinde the average fall of rain was about 5 inches, which was very small; but it fell heavily, and in a short period, seldom extending over more than three days, for four, or five hours each day. Though the water passed slowly over the line, the traffic need not be stopped; and, in fact, it was not stopped during the last rainy season, although the water was 9 inches deep over the rails; after the water had passed away, which it did in the course of a few hours, the railway remained in as perfect condition as before. In cases of this kind, only good broken stone ballast should be used.

April 21, 1863.

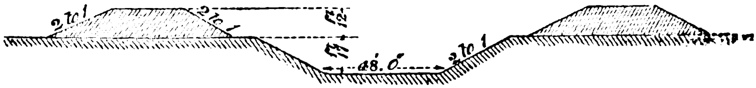
JOHN HAWKSHAW, President,
in the Chair.

No. 1,092.—"Account of the Cofferdam, the Syphons, and other works, constructed in consequence of the failure of the St. Germains' Sluice of the Middle Level Drainage." By JOHN HAWKSHAW, F.R.S., President Inst. C.E.

AT one of the meetings of the Institution last year, the Author was requested to give some account of the works proposed to be constructed, consequent upon the failure of the Outfall or St. Germains' Sluice, of the Middle Level Drainage. The disaster having then so recently occurred, the Author, for obvious reasons, refrained from complying with that request; but he stated that at some subsequent time, he would bring the subject before the Institution, in a Paper descriptive of the works. This he proposes now to do.

The original St. Germains' Sluice was situated at the confluence of the Middle Level main outfall drain with the River Ouse, near the upper end of the Eau Brink Cut. This drain was made in 1847, from the designs and under the direction of Messrs. Walker, Burges, and Cooper; but it was not until 1857, that it was deepened to the full extent originally contemplated by them. The success of that work, in improving the drainage of the Middle Level was, as is well known, most satisfactory. The drain, as thus deepened in 1857, has at its lower end a bottom width of 48 feet, the side slopes being 2 to 1. The level of the bottom is 7 feet under low water of spring tides in the River Ouse, at the point where the drain enters that river. The rise of the tide in the Ouse at that point is about 19 feet at spring tides, and the level of the cill of the St. Germains' Sluice is 6 feet below low water of spring tides. The section of the drain near its lower end is shown in Fig. 1. The bed of the drain is there of soft

Fig. 1.



Section of Middle Level Drain near its lower end.

blue clay, and the sides, from the bottom of the drain to the surface of the ground, consist of variable thicknesses of soft blue clay, peat, yellow clay, and surface-soil. Of these materials the side banks above the level of the ground are composed.

On the 4th of May, 1862, the St. Germains' Sluice gave way, thereby admitting the tidal waters from the River Ouse into the drain, which rushed up, and again poured out of the drain with great velocity, and throughout a distance of upwards of 20 miles they ebbed and flowed. This state of things lasted for a few days, during which time much attention was devoted to the banks, and several minor breaches were successfully stopped; but at length the western bank of the Middle Level Drain burst, at a point about 4 miles from the St. Germains' Sluice, inundating upwards of 9 square miles, or about 6,000 acres of land. (Plate 14.)

Immediately on the failure of the sluice the late Mr. Walker, (Past-President Inst. C.E.) was consulted by the Middle Level Drainage Commissioners; but as that gentleman was unable, from advanced age and failing health, to undertake the operations that were urgently needed, he advised the Commissioners to request the Author to act in the matter; and full instructions were given to do whatever was considered necessary to shut out the tidal waters, regardless of expense. In order to expedite the organisation of a staff of men, and to obtain immediate possession of the plant and materials necessary for carrying on the operations, the Author secured the services of Mr. J. T. Leather (Assoc. Inst. C.E.) as contractor. That gentleman was fitted, from his extensive experience, to carry out the Author's plans, which he did with much vigour and judgment. In this he was ably aided by his assistant, Mr. E. P. Smith. Mr. Alexander G. Linn, (Assoc. Inst. C.E.) was, at the Author's request, appointed Resident Engineer, a position he was well qualified, from his previous career and experience, to undertake, and the duties of which he performed in a highly creditable manner.

Previous to the Author's assuming the direction of the works, and directly after the failure of the sluice, an earthwork dam was commenced, which was attempted to be thrown across the drain at a spot about 500 yards from the fallen sluice. This dam was not immediately relinquished, but its construction was pursued by sinking horizontal cradles of fascines weighted with clunch (a hard chalk stone, procured in Suffolk and Cambridgeshire), and by the use of bags filled with clay, the Author not wishing to abandon an experiment, which he did not originate, without having fairly tried it. It is clear, moreover, that if the dam had been carried up even to a moderate height, which was the utmost the Author ever expected, or desired to accomplish, it would have had the effect of shutting out a certain quantity of tidal water, which would to that extent have relieved the banks of the drain, and have assisted the construction of the permanent cofferdam. On the other hand, by continuing this dam, the introduction of successive layers would pen up an increased quantity of water in the drain; and the more it was raised, the greater would be the scour from the water flowing over it at ebb tide, which scour was considerable when the dam was only raised a few feet. Numerous barges also were required in its construction, any one of which would, if it had broken loose when the tide was running up the drain, have ruined the permanent cofferdam. Great caution was therefore necessary in pursuing its construction; and not long after the permanent cofferdam was commenced, the Author determined to relinquish altogether proceeding with the earthwork and cradle dam, tidal observations having shown that it was unnecessary, when the construction of the permanent cofferdam had advanced to a certain stage. There is no doubt, that the system of raising such a dam by cradles of fascines might be introduced with advantage, in many situations, and under certain circumstances. The Author intrusted the superintendence of sinking the cradles to Mr. Müller, who had considerable experience in raising banks in this manner, and who described the process in a Paper read before the Institution during the last session.[1]

COFFERDAM.

Immediately on receiving instructions from the Commissioners to do whatever might be considered necessary to shut out the tidal waters, the Author determined to construct a permanent cofferdam of pile-work across the drain, as the only plan that was likely effectually to answer the desired end. His original intention was to use the road-bridge spanning the drain about 1,000 yards from the fallen sluice, as a staging from which to drive the piles; but the work was scarcely commenced before the bridge, which was a timber structure, was destroyed by a barge breaking loose and running against it. The site finally fixed upon was about 120 yards to the north of the bridge, and that distance nearer the fallen sluice. Figs. 1, 2, 3, and 4, Plate 15, show the dam as constructed.

It will be desirable, however, before proceeding to describe the dam, to give some particulars relative to the levels of the water in the River Ouse and in the drain. The level of high water of spring tides in the river is, as before mentioned, about 19 feet above low water, but it was not more than 9 feet in the inundated fen, where, owing to the large area of the inundation, the rise and fall of the tide did not exceed 6 inches. The only inerval of repose, therefore, was when the water in the Ouse was at the level of the water in the fen. Fig. 5, Plate 15, is a diagram explanatory of the tidal action. This interval of repose was of very short duration. A few minutes scarcely elapsed before an inward or outward current (according to the state of the tide in the Ouse) became perceptible, which current rapidly increased in intensity. The velocity of the tide up the drain, and again out of the drain, amounted to about 6 miles per hour at spring tides, and 4 miles per hour at neap tides. The depth of water in the drain below low water spring tides was 7 feet; but the bottom of the drain, in the neighbourhood of the dam, having been scoured away about 2 feet, the depth there, at slack water, was about 17½ feet. The material composing the drain and the banks being of so soft a nature, and the velocity of the current being so great, it was clear that much caution would have to be exercised, throughout any operations that might have to be undertaken, to guard as much as possible against the effects of the scour.

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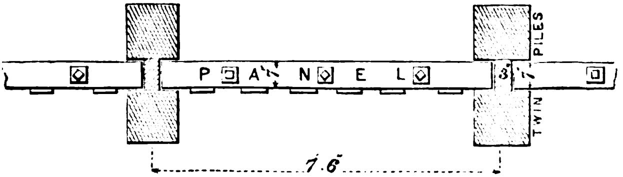
[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxi., p. 466.

The cofferdam, which was commenced on the 16th May, may be thus described:—Temporary piles were screwed into the ground in the first instance, and a platform was erected thereon, to form a staging for the pile-driving engines. When this was done, the permanent pile-work was commenced, by driving two rows of sheet-piling, 25 feet apart, transversely down the slope of the drain on each side. This sheet-piling extended from the centres of the banks to within about 20 feet of the bottom of the drain, leaving a space of 20 feet on each slope and of 48 feet (the bottom horizontal width of the drain), together equal to a central space of 88 feet of cofferdam to be completed. This portion of the dam was thus constructed (Fig. 2.):—Piles of whole timbers were driven on each side, so that when in place they would be in pairs, 7 feet 6 inches apart, from centre to centre. The piles in each pair were placed back to back, a space being left between them of 7 inches, this distance being preserved by a central piece 7 inches by 3 inches. These piles were driven separately, one of the piles, with the distance-piece attached, being first driven, and afterwards the second pile. The grooves thus left

Fig. 2.



Plan showing the Construction of the Central part of the Cofferdam.

were for the reception of sliding panels, to be used in order to fill up the spaces between these several twin piles. These piles could only be pitched during the few minutes of slack water. Waling pieces .of whole timbers were fixed to the inside and the outside, both at the top, and also as near to the low water level as possible. As the piles were driven, proper struts and ties were inserted to stiffen and strengthen the dam, and strongly framed raking struts were fixed, abutting against the dam and against abutments, composed of piles backed with concrete, on the land. The struts, ties, and raking struts will be clearly understood by reference to the drawings of the dam. (Plate 15, Figs. 1, 2, 3, and 4.) The panels are composed of a series of timbers (7 inches thick, and of the length necessary to enable them to slide into the grooves), fastened together by bolts 1¼ inch diameter, and further strengthened and weighted by flat wrought-iron plates on one side, each plate being 6 inches wide by 1 inch thick. In order to put these panels in place, a frame (Plate 15, Figs. 1, 3, and 4) was erected, from which they were suspended, and from which they could be lowered, and raised again if necessary, by pulleys.

The rush of water through the dam, which was considerable before the piles for the panels and the walings were erected, was materially increased when they were in place,—so much so, that there was at times a difference of level of 4 feet, or 5 feet between the water on the two sides of the dam. Already the precaution had been taken of throwing in sacks of clay, with gravel, puddle, and stone (kept in place by footings of clunch) on the upper and lower sides, forming aprons extending the whole width of the drain, and for some distance up the slopes. It now became of the utmost importance carefully to watch these aprons, and also the centre of the dam between the two rows of piles, where, from the necessity which existed of depositing in that space nothing but material impervious to water, there was an increased difficulty in maintaining the bottom from being scoured away. In order to ascertain the state of the aprons and of the centre of the dam, soundings were made, and, for the purpose of throwing in materials, stages were erected. The drain throughout had also to be carefully watched, as the soundings revealed the existence of large holes in the bottom, as well as of considerable scour. In one place the drain had been scoured to a depth of 15 feet from its original bed, maintaining this depth for a length of not less than ¼ mile; and at other places it was discovered that the cast-iron culverts, some of which were of large size, passing originally several feet under the bottom of the drain, had been laid bare. Only a limited quantity of stone was thrown into the centre of the dam, lest it should prevent the clay being afterwards made perfectly water-tight, and should increase the difficulty of driving the piles that yet remained to be put in place, at the back of the panels on the lower side. Great quantities of puddle, however, were cast into the dam at slack water; but most of this was washed away by the rush of water through it, which acquired a velocity of 8 to 9 miles an hour; and it was only with the utmost difficulty, and by incessantly persevering with this operation, that the level of the bottom of the inside of the dam could be maintained at the same level as the bottom of the drain; all attempts to accumulate material within the dam above that level proving ineffectual. At this period it became very difficult to maintain the aprons on the outside, and with the utmost exertion they could only be raised about a foot above the bottom of the drain at their junction with the dam, and for some length from it, gradually increasing in height from this latter point to the end of the apron, where the footings of clunch were made.

The panels in the first, or lower tier were each 7 feet deep. They were pointed at the lower end, so that they could be driven down some depth into the mud; and when all those of the first set were driven, another set was put in. These latter were of variable depths, inasmuch as the first series could not all be driven to the same level, and the lengths of the second set were so arranged as to raise the panelling uniformly to the level of about low water of spring tides. Whilst the panels were being driven, and after they were down, the operation of throwing in sacks of clay and gravel, both on the inside and the outside of the dam, was persevered in; and although the aprons on the upper and on the lower sides were by this means extended, and raised to the height of the panels, nothing remained in the inside of the dam excepting a few sacks of gravel, which were thrown in close to the panels to prevent any 'blowing' from taking place.

It now became clear, that the only practicable mode of excluding the water was to shut in the remainder of the dam at one operation, and to rely on its strength for resisting the pressure that would come upon it, before it could be finally completed. As before observed, it had been previously well strutted both on the inside and on the outside. It was necessary to do this at still water, when there would be a small differential head for the dam to sustain; and, in order to accomplish the object, the panelling, which was required to be 12 feet deep, was suspended from the scaffolding (Plate 15, Fig. 3) on each side of the dam, so as to be dropped into place at slack water.

The first attempt to close the dam, made on the 10th June, 1862, resulted in failure, from the fracture of three of the twin piles (marked X, Plate 15, Fig. 4) on the lower side of the dam, owing probably to their having been injured in driving, and in giving way they released some of the bottom panels. These failed after the tide had receded 3 inches, and when there was a head of 8 feet of water. The other panels were readily lifted up and removed; but a delay was occasioned, as the damage had to be made good, which was done by driving sheet-piling (marked Z, Plate 15, Fig. 4) up to the level of the lower waling, thereby filling in the spaces between and adjoining the broken piles. The tendency of this was, of course, still further to contract the waterway; but it was considered the most desirable course to adopt, as, upon a diver being sent down, it was found that the ground had been much disturbed, by the tearing out of the panels between the broken piles. The second attempt was therefore postponed until the succeeding neap tides; but in addition to the work that had to be performed, the interval was taken advantage of to meet and provide against every contingency that might arise. The first attempt was made at still water of flood tide, as the dam would have to sustain a somewhat smaller differential head at high water than at low water, and by the time the tide had ebbed to its lowest point, the dam would have been filled in to a considerable extent. The second attempt (made on the 19th June) proved a complete success. The panels were again slung ready to be dropped at slack water, but this time the operation was attempted at low water of ebb tide as being more convenient, the difference of the head at high water and at low water not being considered of sufficient importance to counterbalance other advantages. The process of lowering the panels lasted about twenty minutes, and immediately this was effected, the inside was filled with clay, and with sacks of gravel, clunch being thrown into the centre. The aprons on the upper and the lower sides were at the same time raised and extended. About 3,000 yards of clay with several hundred sacks of gravel and clunch were prepared for the operation, and 800 men were in readiness to put these materials in place, from several barrow-roads and waggon-roads; and so perfect were the arrangements, that the raising of the dam inside was kept in advance of the rise of the tide, and before high water the operation was completed. The contrast between the rush of water before, and the calm after, the operation, was remarkable. The tide rose quietly, and the dam, as thus far constructed, did not exhibit the slightest indication of failure, or weakness.

After these panels were placed, sheet-piling was driven behind them on the lower side of the dam, thereby filling in all the spaces between the twin piles, and converting the lower side into one continuous row of sheet-piling, and the dam was further completed without any trouble, or anxiety. In addition to the piles before referred to, extra piles were driven at the sides of some of the twin piles, where it was imagined the panels might not have a sufficient hold. With these exceptions, and one, or two minor alterations, which suggested themselves as the work progressed, the dam was constructed in every respect in the manner, in the order, and to the extent, originally intended by the Author. The cofferdam was commenced on the 16th May, and the tidal waters were shut out on the 19th June, 1862. Appendix A (page 509) contains the quantities of the several kinds of material used in the construction of the cofferdam and in the syphons.

SYPHONS.

During the time the cofferdam was being constructed, serious attention was given to the means to be adopted for the future drainage of the Middle Level. After a careful consideration of this question, the Author came to the conclusion that, in addition to such drainage as could be obtained through Salter's Lode Sluice, the old outlet into the Ouse, — the drain leading to which had to be widened, cleared out, and re-opened by the removal of a bank existing across it,—syphon pipes should be laid over the cofferdam, and that nothing should be done as to the erection of a new sluice, until these latter had been fairly tried. The Author had occasion, in 1839, to enlarge the capacity of the reservoir for supplying the Manchester, Bolton, and Bury Canal with water, which was effected by increasing the height of the reservoir embankment. The old outlet, which passed under the embankment, being of insufficient capacity, he adopted a syphon passing over it, for an additional outlet; so that the experiment of discharging water by the action of the syphon was not to him a novel one. It must here be mentioned that, immediately after the cofferdam was closed, feeling it would be impossible to continue to devote as much time to the works as he had hitherto done, the Commissioners, at the Author's request, associated with him Mr. Thomas E. Harrison, (M. Inst. C.E.) who has since continued to act with him.

The syphons are shown in Plate 16. They differ in no respect from the original design and intention of the Author, excepting in the arrangement of the valves. In the first design, a single valve was placed in a box at the top of the syphon, and in the design as executed, a valve was placed at each end, for reasons which will presently appear. The number of syphons at present erected is sixteen. These are laid across the dam at an inclination of 2 to 1 on either side, and horizontally over the top; each end being terminated by a horizontal length containing the upper and the lower valves. The upper surface of these bottom horizontal lengths is laid at a level of 1 foot 6 inches under low water of spring tides,—so that the ends of the syphons are always under water,—and the top of the syphon is 20 feet above the same level.

The total length of each syphon is about 150 feet. The syphons are of cast iron, 3 feet 6 inches internal diameter, put together in lengths (exclusive of the irregular pieces) of 12 feet, and have spigot and socket ends and lead joints. Four bosses, or lugs are cast on the ends of the several lengths, for the purpose of bolting them together with 1½-inch bolts. The thickness of the metal in the syphons (excepting at the socket ends, where it is thicker) is 1⅛ inch. The syphons rest on the top of the dam and on inclined framework, supported on piles on either side. The piles, which are 14 inches square, are driven so as to be underneath each of the joints of the pipes composing the syphons. These piles are connected together by a horizontal transverse cill, and each syphon rests on whole timbers 1 foot 9 inches apart in the clear, and bolted to the cill. Underneath the extreme ends of the syphons, a row of sheet-piling of whole timbers is driven across the drain, the sheet-piling being properly hollowed out to receive and support the terminal lengths.

The space occupied by the inclined framework between this sheet-piling on each side and the dam, is filled in above the apron that was formed to resist the scour, and up to the underside of the syphons, with clunch, clay, and gravel, thus forming a solid and impervious embankment. The bottom of the dam, at the inlet and outlet of the syphons, is protected by substantial permanent aprons extending across the drain. These aprons are shown in Plate 16, Figs. 1 and 2. The lower parts of the syphons and the aprons were laid by means of dams, consisting of close sheet-piling surmounted by slackers, or sluices. These dams were about 90 feet long, and were thrown across the drain 30 feet from the ends of the syphons. From near their extremities, two parallel rows of sheet-piling, (Plate 16, Figs. 1 and 2,) were driven towards the dam, to within 25 feet of it on the lower side and 35 feet on the upper side. The lower apron extends from the sheet-piling at the termination of the syphons to the sheet-piling of the half-tide dam, and is 30 feet long. It consists, for the first 20 feet of its length nearer the syphons, of piles, 5 feet apart, driven into the ground, and surmounted by cills. The ground, from the top of the cills, is excavated to a depth of 2 feet 6 inches, and the space is filled in with concrete, to the underside of a layer of close planking 4 inches thick, which is spiked to the cills. The remaining 10 feet of this apron, to the sheet-piling of the half-tide dam, is of concrete 2 feet 6 inches deep. The sheet piling of the lower half-tide dam was cut off at the top of the concrete, so as to protect the ends of the aprons from injury and scour. The upper apron is 10 feet long, and consists of piles 5 feet apart, driven into the ground, and surmounted by cills to which close planking, 4 inches thick, is spiked; the toe of this apron being pitched, (Plate 16, Figs. 1 and 2).

Both at the inlet and the outlet of the syphons, a row of sheet piles is driven on each side, inclining towards each other, and contracting the channel to a width of 60 feet. This is for the purpose of keeping the 'wash' off the slopes of the drain.

The upper, or inlet valve (Plate 16, Figs. 4, 5, and 6) consists simply of a flap of teak wood working inwards, and the lower valve (Plate 16, Figs. 7 and 8) is of cast iron, working outwards, and is fitted with a balance-weight. The syphons are put into action by exhausting the air from the inside, by means of an air-pump worked by a steam-engine. This is placed on the western side of the drain, and near to the dam. A horizontal flanged pipe, 10 inches diameter, runs transversely across the dam, over its centre, at a height of 6 feet from the top of the syphons; and vertical pipes, provided with slide cocks, connect each syphon with this horizontal pipe, and with the air-pump. By means of the slide cocks, each syphon can be shut off at pleasure, or be brought into operation when required. Some of the syphons are provided with glass gauges attached to the centre of the sides, and to the vertical pipes at a point above the slide cocks. It can thus be seen when the syphons are full of water. Three brass taps, 1¾ inch diameter, are fitted into the horizontal flanged pipe at the extreme end, for the purpose of admitting air when required, and thus readily stopping, or regulating the working of the syphons. The air-pump has three cylinders, worked together by a three-throw cranked shaft. Each cylinder is 15 inches diameter, and the length of the stroke is 18 inches. The engine is of 10-horse power, and high pressure; the diameter of the cylinder being 12 inches, and the length of the stroke 20 inches The syphons were cast by Messrs. Cochrane and Co., of Woodside Ironworks, near Dudley; and the steam-engine and air-pump were manufactured by Messrs. Easton, Amos, and Sons, of Southwark.

The reason for adopting two valves in the syphons instead of one, as the Author originally intended, was for the purpose of enabling them to be put into operation, either by exhausting the air, or by filling them with water should there be any necessity for it. The inlet valve, being a loose hanging flap of wood, opens inwards as soon as the outward is the preponderating pressure. The outlet valve turns on a hinge at the top, and is balanced; it is rendered capable of resisting an interior pressure, by means of a bridle which holds it fast, but which can readily be released, when the valve is converted into a flap opening outwards. In filling the syphons with water, the same machinery would be employed as is used for exhausting the air, and the water would be pumped up into a reservoir, where it would be in store, ready to be turned into the syphons when needed. For the purpose of controlling the operations connected with the raising and lowering of the outlet valves, a chain is attached to each, worked by a small crab, placed on the top of the dam. At present, the only method that has been tried to work the syphons has been to exhaust the air. The inlet and outlet valves are so arranged, that they can readily be drawn out should it be necessary.

On the lower side the syphons, up to the level of high water neap tides, are protected by a rubble deposit of clunch, extending from the centre to 15 inches above the top of the syphons; the surface of the clunch is pitched with Wansford rubble, 9 inches deep, the pitching being continued to the end of the inclined pilework, (Plate 16, Figs. 1 and 2). The lower part of the syphons, on the upper side, is covered with puddle to a depth of 15 inches above the syphons, this puddle being similarly pitched with Wansford rubble, also 9 inches deep. The upper part of the syphons on both sides is covered with puddle to a depth of 18 inches, on which grass sods are laid, and on the top of the dam a hut is erected, into which steam heating-pipes, 4 inches inside diameter, communicating with the boiler, are placed. By these means the water in the syphons and pipes can be protected from frost. A grating and an ice breaker are placed across the drain in front of the syphons, at the upper end. In Appendix B (page 509) some examples of the results of the working of the syphons are given.

STOPPING THE BREACH, AND CONCLUDING REMARKS.

After the breach occurred, it soon became evident, that all attempts to stop it should be abandoned. The area flooded was surrounded by banks, which confined the mischief within limits, as long as those banks held good. Any attempt to stop the breach, until the tidal waters could be excluded, would only have increased the evil, by causing breaches in other places when still greater damage would have resulted, by the flooding of other lands. The large area flooded, operated as a safety valve, preventing the tidal waters from rising to the height in the drain they otherwise would have done, and actually did rise before the bank burst, and to that extent relieving the banks and preventing breaches at other points.

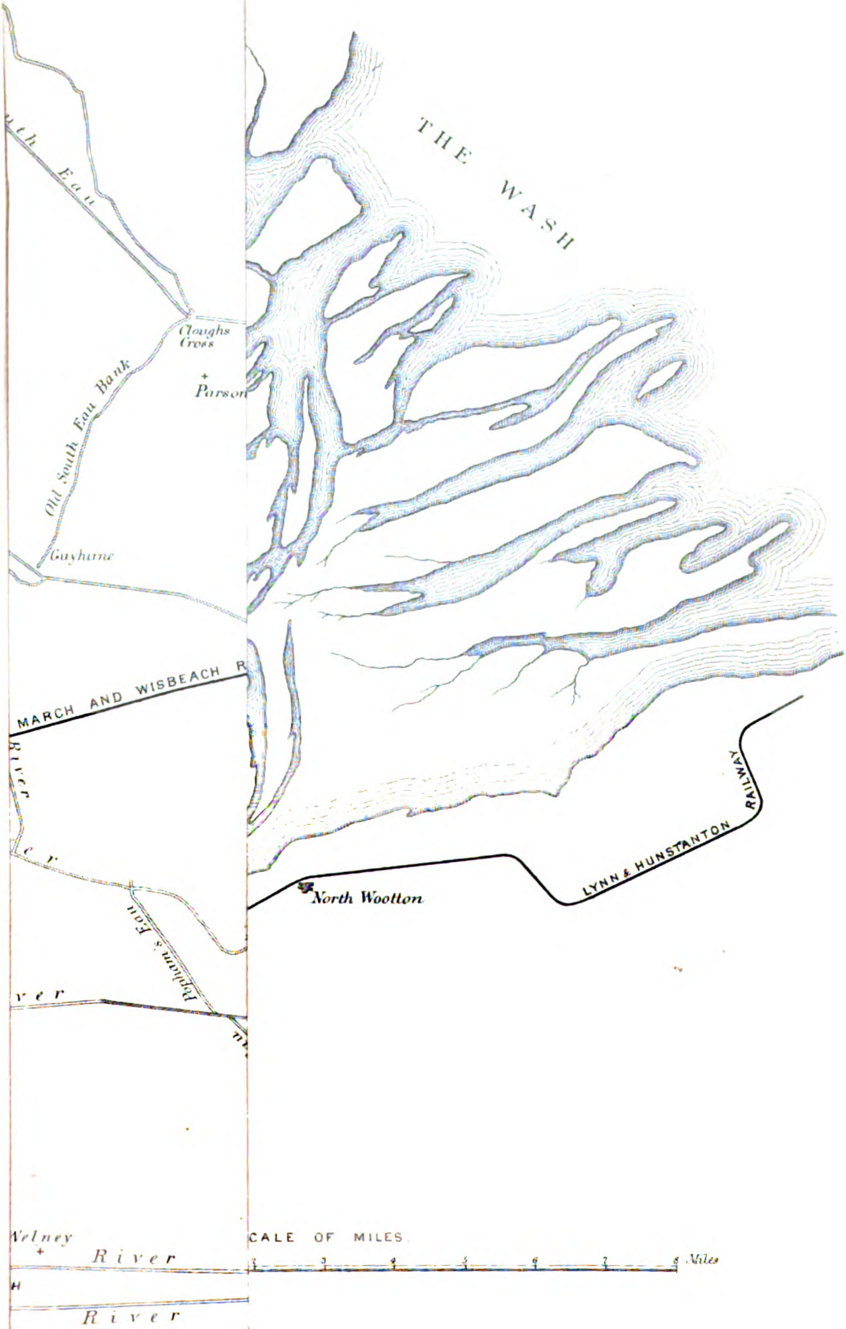
It was not, therefore, until the cofferdam was closed in, and the tidal waters were excluded, that the breach was stopped, and, still water being obtained, this was easily effected. The first operation consisted of tipping stone, so as to form a footing on each side, at the toe of the embankment that had to be raised. This embankment consisted of clay, to the level of the bottom of the drain, so as to make good the material that had been scoured away. The rest of the bank was of clay mixed with a small quantity of clunch, (about half a dozen barge-loads to every 4 feet of depth,) to stiffen and weight it. The total quantity of material used to restore the bank was about 25,000 cubic yards. The bottom of the drain, where the scour had taken place, was also repaired, and the banks generally were put into good order. After the work connected with securing the breach was completed, the water on the inundated land was let off, through the Marshland Smeeth and Fen Drain, and the adjoining Marshland sewer. Since the dam has been closed, much attention has been devoted to thoroughly securing and making good the banks of the drain between the dam and the River Ouse, which had been much damaged by the scour, and they had, from time to time, to be secured and repaired. They are now put into good order by clay and fascine work, so as to admit the efflux and reflux of the tidal waters without suffering deterioration.

The Author has only, in conclusion, to remark, that he believes syphons will be found to answer all the purposes of a permanent sluice. The results obtained have hitherto been of a most satisfactory character. They possess moreover the advantage of not rendering the safety of a district dependent on single pairs of gates; for it is clear that, from their independent action, any one, or more of the syphons may be damaged, or destroyed, without injuring the operation of the others, or endangering the district. A good deal of consideration was at one time bestowed on the advisability of making a sluice in the dam, in addition to the erection of syphons. It was thought that in this way an outlet could be established for the land water, in the readiest and most rapid manner, in anticipation of a land flood occurring in the interim, and before the syphons could be brought into operation. The desirability, however, of not interfering with the dam after it had been erected, led to the abandonment of the notion.

The Paper is illustrated by a series of drawings and diagrams from which Plates 14, 15, and 16 and Figs. 1 and 2 have been compiled.

[APPENDIX

COFFERD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North Wootton
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CALE OF MILES
2
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4
5
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7
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Minutes of Procee

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APPENDIX (A).

TOTAL QUANTITIES OF THE SEVERAL KINDS OF MATERIAL USED IN THE CONSTRUCTION OF THE COFFERDAM AND THE SYPHONS.

COFFERDAM.

Timber	90,693 cubic feet.
Iron	75½ tons.
Cement	432 casks.
Clunch	2,444 tons.
Sacks	36,524 in number.

SYPHONS.

The total weight of metal-work in one syphon, exclusive of the pipes and the connections, is 36 tons; and the total weight of metal-work in the sixteen syphons, including the communication and air-pipes, and connections, complete in every respect, is 610 tons.

APPENDIX (B).

WORKING OF SYPHONS.—*6th March*, 1863.

Time.	Gauge above Dam.	Gauge below Dam.	Vacuum.
12·50	5′ 9″ above datum.	1′ 5″ above datum.	11 inches Mercury.
1·0	5·6 ,,	1·5 ,,	13 ,,
1·5	5·3 ,,	1·5 ,,	
1·10	4·10 ,,	1·8 ,,	
1·15	4·8 ,,	1·10 ,,	
1·20	4·6 ,,	1·10 ,,	
1·25	4·6 ,,	1·10 ,,	
1·30	4·5 ,,	1·9 ,,	16 ,,
1·45	4·3 ,,	1·6 ,,	
2·0	4·2 ,,	1·5 ,,	16 ,,
2·15	4·0 ,,	1·3 ,,	
2·30	3·8 ,,	1·2 ,,	16 ,,
2·45	3·2 ,,	1·0 ,,	
3·0	2·10 ,,	0·10 ,,	15 ,,
3·15	2·6 ,,	0·8 ,,	
3·30	2·4 ,,	0·7 ,,	14 ,,
3·45	2·1 ,,	0·6 ,,	
4·0	1·10 ,,	0·5 ,,	14 ,,
4·15	1·10 ,,	0·11 ,,	
4·30	2·0 ,,	1·11 ,,	14 ,,
4·35	2·2 ,,	2·2 ,,	

7th March, 1863.

Time.	Gauge above Dam.	Gauge below Dam.	Vacuum.
12·50	1·11 above datum.	1·10 above datum.	14 inches Mercury.
1·0	1·10 „	1·6 „	14 „
1·15	1·8 „	1·3 „	
1·30	1·5 „	1·0 „	18 „
1·45	1·4 „	0·9 „	
2·0	1·2 „	0·7 „	18 „
2·15	1·0 „	0·6 „	
2·30	0·10 „	0·4 „	17 „
2·45	0·8 „	0·2 „	
3·0	0·6 „	0·0 „	16 „
3·15	0·4 „	0·1 below datum.	
3·30	0·2 „	0·3 „	17 „
3·45	0·1 „	0·4 „	
4·0	0·0 „	0·6 „	17 „
4·15	0·1 below datum.	0·7 „	
4·30	0·1 „	0·8 „	17 „
4·45	0·2 „	0·9 „	
5·0	0·2 „	0·2 „	15 „

8th March, 1863.

12·30	4·11	4·10	12 inches Mercury.
12·45	4·8	4·4	
1·0	4·6	3·10	14 „
1·15	4·4	3·5	
1·30	4·2	3·0	15 „
1·45	4·0	2·7	
2·0	3·10	2·3	16 „
2·15	3·6	1·10	
2·30	3·4	1·6	16 „
2·45	3·0	1·3	
3·0	2·9	1·2	16 „
3·15	2·6	1·0	
3·30	2·3	0·11	16 „
3·45	2·1	0·8	
4·0	1·10	0·7	16 „
4·15	1·7	0·6	
4·30	1·4	0·4	16 „
4·45	1·2	0·2	
5·0	1·1	0·2	16 „
5·15	0·11	0·6	
5·30	1·3	1·3	16 „

NOTE.—During the time the syphons were working, the doors at the Outwell Sluice were closed. The following is the capacity per foot in height above datum, of the drain between the syphons and the Outwell Sluice:—

Between datum and 1 foot above		3,008,003	cubic feet
,,	1 foot and 2 feet above datum	3,165,865	,,
,,	2 feet and 3 feet ,,	3,411,652	,,
,,	3 feet and 4 feet ,,	3,681,918	,,
,,	4 feet and 5 feet ,,	4,005,962	,,
,,	5 feet and 6 feet ,,	4,253,012	,,
,,	6 feet and 7 feet ,,	4,567,515	,,
,,	7 feet and 8 feet ,,	4,886,176	,,
,,	8 feet and 9 feet ,,	5,047,941	,,
,,	9 feet and 10 feet ,,	5,273,587	,,

It having been represented that it might be inconvenient, while the matters relating to the Middle Level Drainage were under litigation, to discuss the questions raised in the Paper by the President, it was resolved—

That the discussion upon Mr. Hawkshaw's Paper, "On the Cofferdam and Syphons, Middle Level," should be abandoned.

April 28, 1863.

JOHN HAWKSHAW, President,
in the Chair.

No. 1,093.—"The Charing Cross Bridge."[1] By HARRISON HAYTER, M. Inst. C.E.

GENERAL DESCRIPTION.

THE Charing Cross Bridge is being erected for the purpose of carrying the Charing Cross Railway across the river Thames, under the provisions of an Act which received the Royal Assent on the 8th of August, 1859. It occupies the site of the Hungerford Suspension Bridge for foot-passengers, which was built by the late Mr. I. K. Brunel, and the superstructure of which it was necessary to remove; but as the footway had to be maintained, the new bridge, in addition to carrying the rails of the railway, is provided with a footway on either side.

The Charing Cross Bridge comprises nine spans (Plate 17, Fig. 1)—six of 154 feet and three of 100 feet—the centre opening of the Suspension Bridge having been divided into four spans, each of 154 feet; the opening between the Surrey Pier, or Tower, and the abutment into two spans, each also of 154 feet; and the opening between the Middlesex Pier, or Tower, and the abutment into three spans, each of 100 feet. The superstructure over the three latter spans is fan-shaped (Plate 17, Fig. 2), inasmuch as the ground available for the Charing Cross Station being somewhat restricted in length, it was necessary to begin the widening out on the bridge. It was hence found more convenient, for reasons which will be hereafter explained, to divide the opening between the Middlesex Pier and abutment into three spans of 100 feet, instead of into two spans of 154 feet, as on the Surrey side.

The chains and the ironwork of the Hungerford Suspension Bridge are being removed to Clifton, and are to be erected, under the joint supervision of Mr. Hawkshaw, President, Inst. C.E., and Mr. W. H. Barlow, M. Inst. C.E., on the piers which were originally intended to carry the chains of a suspension bridge, and which have so long existed on the banks of the River Avon.

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[1] The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

Mr. Brunel having also been the Engineer of the Clifton Suspension Bridge, the piers of which were erected by him, it is considered fortunate, that the Hungerford chains can be rendered available towards the completion of that work, the span of which does not materially differ from the centre span of the Hungerford Suspension Bridge. The Hungerford chains, however, will have to be strengthened, as the Clifton Bridge is being made wide enough for a carriage roadway, as well as for a footpath on either side.

The superstructure of the Charing Cross Bridge is carried by cylinders, sunk into the bed of the river, and by the piers of the Hungerford Suspension Bridge (Plate 17, Fig. 1), the upper portions of which have been removed, while the lower portions have been added to and modified, so as to adapt them for the railway bridge. The abutments of the Hungerford Suspension Bridge are also retained, but have been considerably lengthened and altered. The width of the river at the bridge is 1,350 feet. The greatest depth of water between the two brick piers is 13 feet below low-water spring tides, and the average depth is about 10 feet. The rise of spring tides is 17½ feet. The level of the rails is 31 feet above Trinity high-water mark, and the clear minimum headway is 25 feet above the same level, that height having to be preserved, to comply with the requirements of the Admiralty and of the Conservators of the River Thames.

The Charing Cross Bridge was designed by Mr. Hawkshaw, President, Inst. C.E., the Engineer to the Railway, and is being carried out under his immediate supervision,—Mr. John H. Stanton, M. Inst. C. E., being the Resident Engineer. Mr. George Wythes is the contractor for the construction of the railway, but he sublet the erection of the Bridge to Messrs. Cochrane and Co., Woodside Ironworks, near Dudley, who, up to the present time, have carried out the work in a satisfactory and creditable manner, the immediate direction of the operations having been intrusted by them to Mr. Joseph Phillips, Assoc. Inst. C.E.

CYLINDERS FOR THE OPENINGS 154 FEET SPAN.

The cylinders, excepting those at the fan end, which will be hereafter described, are 14 feet diameter below, and 10 feet diameter above the ground, the junction between the two sizes being effected by an intermediate conical length (Plate 17, Fig. 3). There are four piers (three intervening between the towers of the Hungerford Suspension Bridge and one between the tower and the abutment on the Surrey side) formed of cylinders of the above diameters, and each of the piers consists of two cylinders, 49 feet 4 inches apart, from centre to centre. They are of cast iron, and are shown in detail in Plate 17, Figs. 5, 6, and 7. The circumference of each cylinder of 14 feet diameter, is divided into seven equal parts or segments, the segments being generally 9 feet high; that of the cylinders 10 feet diameter, is divided into five equal parts or segments, each segment being also generally 9 feet high; whilst that of the intermediate or conical piece is similarly divided into five equal parts or segments, each 9 feet high. The segments are fastened together inside, by bolts 1¼ inch diameter, passing through flanges cast on the top, bottom, and sides of the segments. A horizontal interior strengthening rib is cast on the middle of each segment. All the joints of the segments, both horizontal and vertical, are planed, and spaces are left in the inside between the flanges for the introduction of iron cement, to render the joints water-tight. The vertical joints of the segments in each of the two lengths of different diameters respectively are over one another. There are thus continuous vertical lines of ribs, securing a strong columnar arrangement. The horizontal joints can also be made to fit better in this way than by breaking the vertical joints. The thickness of the metal in these cylinders is 1⅛ inch throughout, excepting in the bottom length where it is 1½ inch.

Sinking the Cylinders.

The staging for sinking the cylinders consists of piles erected round the pier, supporting a stage or platform at the level of 4 feet above high-water mark. When this staging was in its place, an opening of 45 feet was left between two adjoining piers; but in order that the navigation might not be interrupted, only two openings, in the space between the two brick piers, were allowed to be narrowed to that extent at the same time. The staging used in the two Surrey openings, which is generally similar to that employed for the other openings of the same span, is shown in Plate 1, Figs. 8 and 9. The part up to the lower platform was erected for the purpose of sinking the cylinders. This was afterwards carried up, as shown, and the 45 feet opening spanned, for the purpose of erecting the girders, as will be hereafter explained.

The strata through which the cylinders are sunk (Plate 17, Fig. 1) consist of mud and gravel, of varying thicknesses, overlying the London clay. The cylinders were sunk by excavating the material from the inside, by means of divers with helmets, and then by weighting them as the excavation proceeded, until they had passed through all the porous material, and had entered a few feet into the solid London clay. The water was then pumped out, and the cylinder was kept dry for the rest of the operation, very little pumping being required. The sinking was then proceeded with, by excavating the material and by weighting the cylinders. The weight with which it was found necessary to load the cylinders, in order to overcome the friction of the sides, and to sink them to their final depth, averaged about 150 tons. The London clay at the base of the cylinders was of a hard character, of a dark-blue colour, and it extended to a depth far below the level at which the cylinders were founded.

The cylinders constituting the pier between the Surrey abutment and the brick pier, are sunk to a depth of 52 feet below Trinity high-water mark. Those between the two brick piers are sunk to a depth of 62 feet below the same level, excepting the up-stream cylinder of the middle pier, which had to be sunk 10 feet deeper, on account of some of the material through which it passed being softer than that met with at the sites of the other cylinders.

The Act for the railway provided, that the foundations of the bridge should be laid at such depth, as would admit of the river being deepened, at any subsequent time, to 30 feet below Trinity high-water mark.

Filling-in the Cylinders, and Weighting.

After the cylinders had been sunk, and the material had been excavated, they were filled with concrete up to where the conical part commences, and with brickwork from that level to the underside of the granite bearing blocks occupying the top of each cylinder. The concrete was composed of Thames gravel or ballast, that obtained from the excavation from the inside of the cylinders being used, so far as it was suitable and sufficient, the remainder of the gravel being purchased from the Conservators of the River Thames. This was mixed with the best Portland cement, in the proportion of one part of cement to seven parts of gravel. The brickwork is generally composed of the best paviour bricks, set in Portland cement mortar, in the proportion of one part of cement to two parts and a half of sand.

Before the lengths above high-water were put on, the cylinders, after they had been filled with the concrete and brickwork, were weighted with a load of about 450 tons, excepting the two cylinders in the pier nearest to the Surrey side, which were the first sunk, and which Mr. Hawkshaw required to be weighted each with 700 tons, that being about the greatest load that could come upon any one cylinder, assuming the four lines of rails on the bridge to be loaded with locomotive engines. Upon the removal of the loads, it was found that each of the cylinders which had been weighted with 700 tons had permanently sunk 4 inches, and each of the others that were loaded with 450 tons had permanently sunk, on an average, nearly 3 inches. The larger loads were applied in order to test the strength of the foundations, and the subsequent smaller loads to bring the cylinders to a bearing, so as to prevent any settlement, after the completion of the bridge, from the weight of the permanent and moving loads. The load was applied by piling the permanent rails of the railway on the cylinders. After it was removed, the top lengths were put on, and were filled in with brickwork, and then the granite bearing blocks, which are from the Cheesewring Quarries, were fixed in place. These blocks are 2 feet 6 inches thick, and are in two equal pieces, which, when together, fill the cylinder, the joint being under and longitudinal with the girders. The granite blocks project 1 inch above the top of the cylinders, in order that the weight may be prevented from coming on the upper edge of the ironwork.

Each pair of cylinders forming a pier is connected together transversely by a wrought-iron box girder, 4 feet deep, strongly attached to the top of each (Plate 18, Fig. 12). This girder also serves the purpose of a cross girder for supporting the roadway. Assuming the four lines of way on the bridge to be loaded with locomotive engines, the pressure on the base of the cylinders would amount to about 8 tons per square foot, and that on the brickwork at the top of the cone, where the cylinder is 10 feet diameter, to about 9 tons per square foot. The former pressure, however, is on the supposition, that no relief is afforded by the friction of the sides against the material through which the cylinders penetrate. If this were taken into account, as it should be, the 8 tons per square foot would be much reduced, and it is clear that this pressure will never be approached.

Superstructure of the Openings 154 feet Span.

The superstructure of each of the openings, 154 feet span, consists of two main girders, underneath which are cross girders (Plate 17, Fig. 3). The main girders are, like the cylinders, 49 feet 4 inches apart from centre to centre transversely, leaving a space between them sufficient for four lines of rails, the roadway platform being supported by the cross girders. For the purpose of carrying the footpaths, each of which is 7 feet wide in the clear, the cross girders extend beyond the main girders, forming a series of cantilevers on each side of the bridge.

Main Girders Spanning the 154 feet Openings.

These girders are of wrought iron. They are not continuous over two or more openings, but are all detached. Each has to support, inclusive of its own weight, a maximum distributed load of about 700 tons. The elevation, sections, and details of these girders are shown in Plate 18, Figs. 1 to 7. The extreme depth of the girders is 14 feet, and the depth between the centres of gravity of the top and bottom members is 12 feet 9 inches. When the girders are loaded with a maximum strain of 4 tons per square inch in compression, and of 5 tons per square inch in extension (which are the limits allowed for the wrought ironwork throughout the bridge), the sectional area in the top, at the centre of the girder, will be somewhat less than 300 square inches, and that in the bottom, excluding the rivet holes, will be somewhat less than 235 square inches; these being the respective central areas of the girders as constructed.

The sides of the girders between the bearings are divided by vertical bars into fourteen equal parts, each division containing a double set of two diagonals crossing each other. These are placed, as nearly as practicable, at an angle of 45° with the top and bottom of the girder; and both the diagonals and the vertical bars are connected to the top and bottom webs by pins of puddled steel. The top and bottom webs of the girders are of boiler-plate, and consist of horizontal tables 4 feet wide at the top and 3 feet wide at the bottom, and of four vertical ribs, the two outer rows being 24 inches deep, and the two inner 21 inches deep. The joints of the plates, in the horizontal tables of the top and bottom webs, are covered by a continuous plate running the whole length of the girder; that in the top being of the same thickness as the plates covered, and that in the bottom one-sixteenth of an inch thicker (Plate 18, Figs. 3, 4, 5, and 6). The joints in the vertical ribs in the top and bottom occur near the pin-holes, and are covered by 1-inch plates, 2 feet 4 inches long, placed on both sides of the ribs, thus forming a good bearing for the pins (Plate 18, Fig. 7). The vertical ribs are united to the horizontal tables by angle-irons, 6 inches by 6 inches, by 1 inch thick in the centre and $\frac{3}{4}$ of an inch thick at the ends, covered at the joints in the usual manner. The rivets used throughout the top and bottom of the girders are 1 inch diameter, and their pitch is about 4 inches.

The aggregate thickness of the plates in the horizontal table of the top in the centre of the girder being $3\frac{1}{8}$ inches, and in the bottom $3\frac{13}{16}$ inches, without the angle-irons, and $4\frac{1}{8}$ inches and $4\frac{13}{16}$ inches respectively, with the angle irons, but excluding the angle-iron covers, it would not have been easy to unite the parts composing such a thickness, by rivets passing through holes punched in the metal. However perfectly the holes may be set out in the first instance, the process of punching always stretches the iron; so that, when the plates are put together, the holes do not come accurately over one another. Neither would they have been truly cylindrical throughout, as they are always, when punched, larger on one side than the other; so that where so many thicknesses had to be united, imperfect riveting would have resulted, unless rimering out to a great extent had been resorted to. Mr. Hawkshaw therefore required the holes to be drilled. This was done by machines designed by Messrs. Cochrane and Co., which were capable of drilling a large number of holes simultaneously. These machines answered their purpose very satisfactorily, and the drilling enabled the riveting to be well and readily done. And while great saving was effected in the cost of putting the work together, it was also found that, where so many holes had to be made, drilling was in itself less costly than punching.

The diagonals which act as ties are of Howard's patent rolled suspension links, each separate tie being composed of two or three links, as required, riveted together. The diagonals acting as struts are each in one solid forging. The struts and the ties have swelled ends for the pins. The struts are united together in pairs, by zigzag bracing of wrought-iron, 4½ inches wide by ¾ inch thick, riveted to them, and by bolts passing through cast-iron distance-pipes. The ties, also in pairs, are not united together; but in the centre of the girders, where the diagonals act both as struts and ties, the pairs are united together in the two central spaces by the zigzag work. The dimensions of the struts vary from 12 inches by 3 inches at the ends, to 6 inches by 2½ inches in the middle, and of the ties from 12 inches by 2½ inches at the ends, to 6 inches by 2 inches in the middle. The turned pins, of puddled steel, were procured from Messrs. John Brown and Co., of Sheffield. They are 7 inches diameter at the ends of the girders, decreasing to 5 inches diameter at the centre, and are 11 feet apart from centre to centre.

At the ends of the girders under consideration, the sides over the supports are boxed, being composed of ⅜-inch plate iron, stiffened by angle and T irons. Where the girders bear upon the brick piers and upon the Surrey abutment, they rest upon roller bed plates, but upon the cylinders, sheet lead only is interposed between the girders and the granite blocks. The force of expansion and contraction will probably cause the cylinders between the brick piers to rock to and fro to a certain but inappreciable extent. The girders were put together in place, on the staging before referred to (Plate 17, Figs. 8 and 9). The top of the girder was put together on the top upper platform, and the bottom of the girder on the top lower platform, the two platforms being kept at the correct distances apart by diagonals, converting the whole into a framework of timber. The supports on the platforms, on which the girders were erected, were accurately adjusted to the proper camber of the girders. The rivet holes in the plates forming the top and bottom of the girders were all drilled at the works of Messrs. Cochrane and Co.

before being sent to London, but the pin-holes were not bored out to the full diameter.

The struts, with the diagonal bracing, were also put together at the works of Messrs. Cochrane and Co., and the pin-holes were bored out to the full size, so that they, and also the ties, were sent up in a complete state. When the top and bottom webs were in place, the struts and the ties were erected, and the pin-holes in the girders were accurately bored out, by means of a boring apparatus worked by a small steam-engine, the gauge of the running wheels of which was so adjusted, that it might work backwards and forwards on the two outer vertical ribs of the lower part of the girder. Great care was taken to insure accuracy in the direction and position of the holes. The pins, after being coated with grease, were forced into the holes, the diameter of the latter being such that the former could only be driven in by exerting a considerable force, a perfect fit being thereby established. The vertical bars dividing the sides into the several spaces are 6 inches wide by 1 inch thick. They have not been taken into account in calculating the strains. They fit on to the ends of the steel pins, and are in pairs, one on either side, and outside the outer vertical ribs of the top and bottom, and are connected together by bolts and distance pipes. The only use they serve is to stiffen the girder to a certain extent.

The ends of the pins are covered with circular castings screwed on, and over the ends, resting on the cylinders, ornamental castings are to be fixed.

The weight of each main girder spanning the 154 feet openings is 190 tons.

One of the main girders was tested, when in place, with a distributed load of 400 tons, and the deflections were accurately taken. The load being very great, and the girder being unconnected transversely, (the cross girders not having been fixed,) great care had to be observed in putting on the weight, which consisted of the rails of the railway. The manner in which it was loaded will be understood from Plate 18, Figs. 15 and 16. The greatest deflection in the centre, when the load was on, was $1\frac{5}{16}$ inch, and the permanent deflection, after the load was removed, was $\frac{1}{2}$ inch. (Plate 18, Fig. 14.) If the girders had been rigidly connected transversely by the cross girders, the deflection would doubtless have been less. This has since been proved to be the case. The whole of the bridge, in its completed state, has been tested by a maximum load, and the greatest deflection of the main girders has not been more than $\frac{3}{4}$ of an inch in the centre.

The plate iron used throughout the bridge was also tested, and the results are given in the Appendix, page 527. These are interesting, as both the extension and the permanent set were carefully taken by an accurate extensometer.

It has been before stated, that the girders are all detached, and not continuous over two or more openings. Mr. Hawkshaw's original intention was to connect the girders spanning the two end openings on the Surrey side, and also to connect the girders spanning the four central openings. As regards the girders spanning the two openings on the Surrey side, it was found that it was not easy to gain the full advantage from continuity, inasmuch as the girders having to support a considerable load, the thickness of the plates in the top and bottom was too great to render it practicable to reduce them to a minimum at the point of contrary flexure. Moreover, the strain on the diagonals would have been greater at the central support than at the end supports, and the uniformity in size of the struts and ties could not have been maintained, had their correct dimensions consequent upon continuity been adopted. It was also desirable not to increase the strain on the diagonals, as the end struts are already large forgings. The same remarks apply, more or less, to the girders spanning the four central openings, although in this case greater advantage would have been gained by continuity. More difficulty, however, would have been experienced in their erection, inasmuch as the Conservators of the River Thames, only allowed the staging to be erected in the river for two of the central openings at one time. It is clear also, that much more trouble would have been incurred in constructing continuous girders over several openings, than in putting together a series of detached girders. In the former case there would be a multitude of dissimilar parts, whilst in the latter all the girders would be duplicates of one another. Better workmanship is thus insured, and at a less cost per ton. In order to ascertain whether any saving of metal would be effected, by the girders being constructed on the continuous or non-continuous system, drawings of both were prepared, and the weights were accurately calculated. The difference was inconsiderable in the case of the side openings, and was not of sufficient importance over the central openings to counterbalance the advantages to be derived from non-continuity; Mr. Hawkshaw therefore determined to abandon the idea of continuity. The Author does not argue from the foregoing, that continuity in girders may not be sometimes, or even as a general rule, desirable. In this, as in most other similar matters, no rules universally applicable can be laid down. In the case under consideration there are exceptional circumstances, which, after being fully investigated and considered, led to the abandonment of continuity.

CROSS GIRDERS FOR THE OPENINGS 154 FEET SPAN.

The cross girders for the openings 154 feet span are shown in Plate 18, Figs. 8, 9, 10, and 11. They are of wrought iron, and are suspended from the main girders. The top and the bottom of that portion of the cross girders between the main girders consist of two plates, 18 inches wide by $\frac{5}{8}$ inch thick. The sides are of lattice-bars united to the top and bottom by two angle irons, 5 inches by 3 inches by $\frac{7}{16}$ inch thick. These cross girders are 4 feet deep in the middle, and 2 feet $1\frac{1}{8}$ inch deep where the cantilevers are united to them outside the main girders, the bottom being fish-bellied, and the top having a camber of $3\frac{1}{2}$ inches in the centre. The lattice-bars are fixed at an angle of about 45° with the top and bottom. The ties are in two bars throughout, and each bar varies from 6 inches by $\frac{1}{2}$ inch at the ends to 4 inches by $\frac{1}{2}$ inch in the middle. The struts are in one bar passing between the two ties, and vary from 6 inches by 1 inch at the ends to 4 inches by 1 inch in the middle. The rivets in the cross girders are $\frac{13}{16}$ inch diameter. The cantilevers decrease from 2 feet $1\frac{1}{8}$ inch deep at their junction with the cross girders to 1 foot 2 inches deep at the extremities. The top and bottom of the cantilevers are composed of two angle irons, $3\frac{1}{2}$ inches by 3 inches by $\frac{1}{2}$ inch thick, and the sides are of lattice-bars also placed at an angle of about 45° with the top and bottom; the ties likewise consist of two bars and the struts of one bar passing between them, each of the former being 2 inches by $\frac{3}{8}$ inch, and the latter 2 inches by $\frac{3}{4}$ inch.

It will be seen, therefore, that the cross girders are generally similar in character to the main girders. They are suspended from the under side of the main girders at the points where the pins occur. They are therefore placed 11 feet apart, from centre to centre. The sides of the cross girders, where they are underneath the main girders, are boxed in with plate iron. They are suspended by four angle irons—two on either side,—and outside the outer vertical ribs of the bottom of each main girder, to which, and to the boxed sides of the cross girder, these angle irons are riveted. By this means a strong and good attachment is established. The cross girders are connected together by wrought iron cross-bracing attached to the centre of each (Plate 19, Fig. 1). Each cross girder, including the two cantilevers, weighs 9 tons. They were tested by erecting two cross girders in the contractor's yard, placed transversely 6 feet apart in the clear, the cantilevers being removed. They were then loaded with 140 tons (equivalent to 70 tons on each girder) distributed over the span. The maximum deflection in the centre, when the load was on, was 1 inch; and the permanent deflection, when the load was removed, was $\frac{1}{4}$ inch. This result would doubtless have been better had the cross girders been in place and rigidly fixed at the ends to the main girders. The whole of the cross girders have since been tested in place with a maximum load, and the deflection has in no case been more than ⅝ inch in the centre.

Fan End.

The superstructure of the three openings, 100 feet span each, of the Fan End is supported by the Middlesex brick pier and by the Middlesex abutment of the bridge, and intermediate to these by piers of cast iron cylinders, that next to the brick pier, consisting of a row of seven cylinders, and that next to the abutment of a row of nine cylinders. In these two rows (Plate 17, Fig. 4, and Plate 19. Fig. 1) the outer cylinders are 10 feet diameter below and 8 feet diameter above the ground, and the inner ones are also 10 feet diameter below but only 6 feet diameter above the ground, the junction between the two lengths of different diameters being effected by a conical length. The circumference of the lower lengths of the cylinders, 10 feet diameter, is divided into segments, which are generally similar, and are connected together in the same way, as the upper lengths of the cylinders already described, of the same diameter, in the piers of the openings 154 feet span. The upper lengths of the outer cylinders 8 feet diameter and of the inner cylinders 6 feet diameter, are not divided into segments, but are cast in pieces complete on the circumference, and 5 feet long. These pieces are fastened together, by bolts 1¼ inch diameter, passing through flanges cast on the top and bottom. All the joints throughout these cylinders are made water-tight in the usual manner by iron cement. The cylinders in these two piers have been sunk in place, precisely in the same manner as the cylinders of the openings of 154 feet span, and to depths averaging about 40 feet below Trinity high-water mark. When in place and when all the material had been excavated from the inside, they were filled with Portland cement concrete to the level of about 5 feet above Trinity high-water mark. It was not considered necessary to fill in the remaining portion of these cylinders.

As some irregularities, or deviations from the perpendicular, occurred in sinking some of the cylinders in the row next the Middlesex brick pier, a horizontal casting, extending over all the cylinders of this row, was bolted to them at about the level of the ground, Plate 17, Fig. 4; on this casting the upper parts of the cylinders of this pier are fixed.

On account of the great width of the Fan, which increases from 49 feet 4 inches from centre to centre of the outside girders at its commencement at the Middlesex brick pier (this being the width between the parallel main girders spanning the 154 feet openings) to 168 feet from centre to centre of the outside girders at the abutment, the system pursued in the other openings, of supporting the roadway on cross girders suspended from outside main girders, was clearly inadmissible. It was also undesirable to introduce intermediate main girders, projecting above the roadway. An unbroken platform is at all times more or less a desideratum, but in close proximity to a large station it is almost a necessity. The roadway over the Fan is, therefore, carried by interior plate girders (Plate 19, Fig. 1,) laid at right angles to the piers and the abutment, and by the outside main girders, which are at the angle of inclination of the Fan. These latter (Plate 19, Figs. 2, 3, 4, and 5,) are of the same depth, and although lighter in all the parts, are generally of the same character, and are fixed at the same level, as the girders of the openings 154 feet span. The faces of the bridge have, therefore, a uniform appearance throughout.

The interior plate girders, where they bear on the cylinders, rest on a bed plate, (Plate 17, Fig. 4, and Plate 19, Figs. 1 and 8,) extending over all the cylinders of each row. They are connected together by cross bracing in the centre of each span, and at points intermediate between the centre and the supports; and where they rest on the Middlesex pier and abutment, are built into the brickwork. The bottom of these girders is at a lower level than the bottom of the outside main girders, inasmuch as it was impossible to obtain sufficient depth without resorting to this arrangement. As it is, the depth of these girders is only 5 feet; or one-twentieth of the span. If the spans in the Fan had been 154 feet, the interior plate girders instead of being one-twentieth would have been less than one-thirtieth of the span. Hence the advantage of introducing the smaller spans of 100 feet. The elevations and sections of the interior plate girders are shown in Plate 19, Figs. 6 and 7. They are of the ordinary construction, and weigh about 26 tons each.

The outside main girders do not make exactly the same angle with the centre line produced of the parallel portion of the bridge. The shape of the Fan is therefore not accurately that of an isosceles triangle—the distance between the centre line of the Fan and the centre line produced of the parallel portion of the bridge, being 7 feet 9 inches at the Middlesex abutment. (Plate 19, Fig. 1.) These outside main girders, which are over the centre of the outside cylinders of the piers, are raised above the interior plate girders by cylindrical making-up pieces of the same diameter (8 feet) as the upper lengths of the outside cylinders. (Plate 17, Fig. 4.) These cylindrical pieces are filled with brickwork in cement, resting on the bed-plate, the top being covered with a bed of an inch in thickness of Portland cement, raised half an inch above the top of the cylinder, and forming the bearing surface of the girders.

The triangular spaces between the outside main girders and the outer interior plate girders are filled in with cross girders, riveted to the sides of the latter, and suspended underneath the former, and are terminated by cantilevers projecting beyond the face girders. (Plate 17, Fig. 4, and Plate 19, Fig. 1.) These cantilevers are similar to those outside the main girders of the 154 feet openings, and like them are placed about 11 feet apart from centre to centre, thus preserving the uniformity.

The girders of the Fan rest directly on their supports, no rollers being interposed, excepting underneath the outside main girders, where they rest on the Middlesex brick pier and abutment; but the bearings for the interior plate girders on the cast-iron bed-plate over the cylinders are planed. The ends of the cylinders on which the bed-plate rests are also planed.

ROADWAY AND FOOTPATH PLATFORMS.

The roadway platform over the openings 154 feet span, consists of planking 4 inches thick, spiked to longitudinal timbers, 15 inches by 15 inches, placed underneath the rails, and bolted to the cross girders. The roadway platform over the Fan End, consists of planking 6 inches thick, secured to the interior plate girders, and to longitudinal timbers spanning the cross girders in the triangular spaces. By abandoning the longitudinal timbers in the Fan, over the shallow interior plate girders, which the arrangement permitted, additional depth was obtained for these. The footpath platform on each side consists throughout of planking 6 inches thick, secured to the top of the cantilevers. The roadway platform is to be covered with tar pavement about 2 inches thick, and the footpath platforms with asphalte 1 inch thick. The longitudinals and the whole of the planking are creosoted, and the latter is grooved and tongued with iron, and caulked with tar and oakum. The rails over the bridge are flat-bottomed, and of the ordinary section. On the outside of the footpath an ornamental railing, of cast iron, is being fixed. (Plate 18, Fig. 13.) A railing of a pattern generally similar will be fixed to the main girders on the inside of the footpaths, to prevent the railway being trespassed upon.

CONCLUDING REMARKS.

The first cylinder of the Charing Cross Bridge was pitched on the 6th of June, 1860. The bridge is on the eve of completion. Its construction will thus have extended over a period of about three years. Some time was necessarily occupied, in consequence of obstacles tending to retard its completion; the principal ones being, the retention of the Suspension Bridge during the construction of the works, because of the necessity for keeping open the footway traffic, which has not been interrupted; the time occupied in the removal of the Suspension Bridge; and also the necessity of almost completing several parts of the bridge before others could be commenced, the extent of staging that was permitted to be in the river at one time being limited.

The total weight of metal work in the bridge will be:

Wrought-iron work, including steel pins .	4,950 tons.
Cast-iron work	1,950 tons.

The total cost of the bridge, including the abutments, will be £180,000. The superficial area of the roadway and of the footpaths being 103,000 square feet, the cost per square foot of roadway will be about £1 15*s.*; and the bridge being 1,375 feet long, the cost per lineal foot will be about £131.

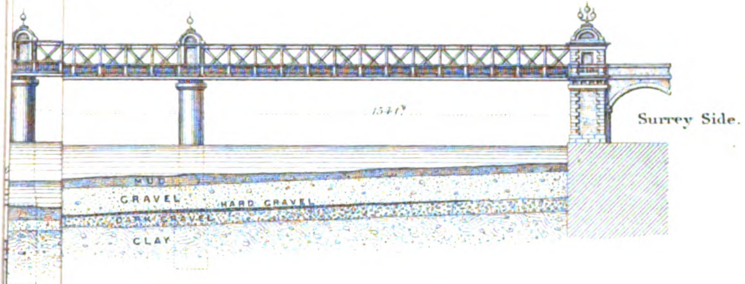
The cylinders of the openings 154 feet span, including the portions in the ground and the portions above the ground, cost, when in place, complete in every respect, and filled with brickwork and concrete, about £22 per lineal foot; the outside cylinders of the piers of the Fan, about £14 per lineal foot; and the inner cylinders of the piers of the Fan, about £12 per lineal foot. The average actual cost of excavating the material from the inside of the cylinders, and depositing it in barges alongside, was about 12*s.* per cubic yard. This was the case whether divers were employed, or whether the material was excavated when the cylinders were dry, inasmuch as in the latter case the material had to be lifted to a greater height.

It is probable, that the cost of the main girders would have been about the same if the sides, instead of being constructed as they have been, had been composed of a number of lattice bars, or had been of ordinary plate work. In the last case, the workmanship would have cost less, but on the other hand there would have been more metal in the sides than in either of the two former cases.

Almost all the parts of the Charing Cross Bridge are open to view, and can be readily reached to be painted, or repaired when needed.

In conclusion, the Author has only to remark, that his desire has been to describe the Charing Cross Bridge as it exists, and as it will be when entirely completed, and the mode of its construction, without asserting that the design is superior to any other, or, assuming that, if best adapted to the site where it has been erected, therefore it would necessarily be equally suitable for any other similar place. In railway structures the great desideratum is evidently to plan a work that is appropriate, and that can be erected at a minimum cost. This has been kept in view throughout, and the Author believes that Mr. Hawkshaw has succeeded in designing a bridge that is well adapted to the situation where it is placed, and for the purpose intended, and its comparatively small cost proves that no outlay has been incurred beyond what was needed.

The Paper is illustrated by a series of drawings and diagrams from which Plates 17, 18, and 19, have been compiled.


154' 0"
MUD
GRAVEL
HARD GRAVEL
DARK GRAVEL
CLAY
Surrey Side.

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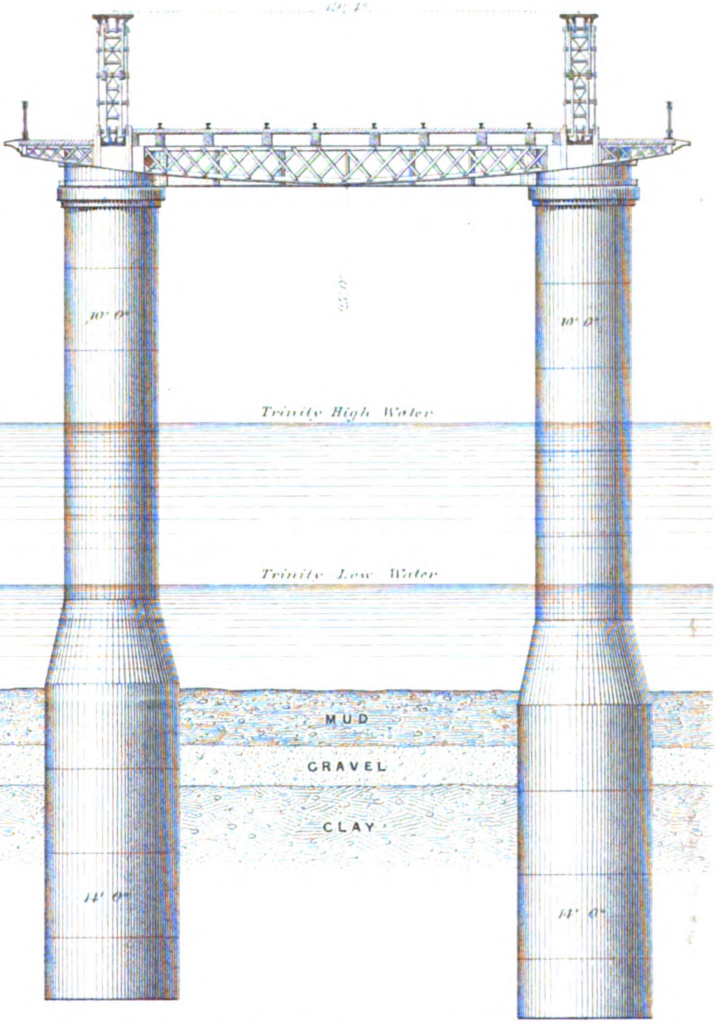
eers. Vol

Fig: 3.


49' 4"
35' 0"
10' 0"
10' 0"
Trinity High Water
Trinity Low Water
MUD
GRAVEL
CLAY
14' 0"
14' 0"

CROSS SECTION OF OPENINGS 154 FEET SPAN.

KELL BROS LITHRS CASTLE ST HOLBORN.

APPENDIX.

Results of Experiments on Plate Iron, of the kind used in the construction of the Charing Cross Bridge.

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Note.—The whole of the Extensions were taken with an Extensometer up to a load of 18 tons, when the Extensometer was removed, the remaining Extensions being taken by compass and scale.

The four Plates operated upon were each reduced to a sectional area of 1 square inch as nearly as possible, the following being the exact dimensions:—Plate in Experiment No. 1, 2·04 × ·51; Plate in Experiment No. 2, 2·04 × ·51; Plate in Experiment No. 3, 2·03 × ·51; Plate in Experiment No. 4, 2·03 × ·51.

All the Extensions were taken after the movement had ceased unless otherwise noted. The load was applied by an Hydraulic Press connected with Naylor's Pressure Gauge.

Load in Tons.	Extension in Inches of One Lineal Foot.				Permanent Set in Inches of One Lineal Foot.			
	Plate No. 1.	Plate No. 2.	Plate No. 3.	Plate No. 4.	Plate No. 1.	Plate No. 2.	Plate No. 3.	Plate No. 4.
2¾	begins to extend	..	..	begins to extend	..	..	..	..
3	..	begins to extend	begins to extend	..	..	..	..	..
10	·010	·009	·008	·009	·000	·000	·000	·000
12	·014	·010	·010	·010	·000	·000	·000	·000
13½	·015	·012	·011	·011	·000	·000	·000	·000
15	·016	·014	·011	·012	·001	·001	·000	·000
16	·025	·035	·013	·015	·011	·021	·002	·001
17	·155	·150	·130	·130	·140	·136	·116	·114
18	·285	·255	·270	·260	·270	·237	·252	·248
19	·360	·330	·310	·290	·360	·330	·310	·298
20	·450	·500	·400	·360	·450	·500	·400	·360
21	·630	·580	·540	·490	·630	·580	·540	·490
22	·750*x*	·750*x*	·710*x*	·650*x*	..	..	..	..
Do.	·820*y*	·820*y*	·800*y*	·710*y*	..	..	..	..
22¾	..	..	Broke	..	..	..	..	..
23	Broke *z*	1·07*x*	..	·900	..	..	..	..
23½	..	Broke	..	Broke	..	..	..	..

x Are Extensions taken at once.
y Are Extensions taken after 2 minutes, when movements had ceased.
z Extension taken at once was 1·07, the plate breaking after the load had been on 1 minute.

The following are the dimensions in inches of the Plates measured at the fracture after breaking:—Plate No. 1, 1·96 × ·48; Plate No. 2, 1·94 × ·47; Plate No. 3, 1·98 × ·48; Plate No. 4, 1·95 × ·47.

Mr. G. H. Phipps said, he had examined this bridge several times during its progress, and he considered the workmanship was the finest he had ever seen. The finish was more like joiners' work than ordinary boiler-plate construction. Although the merits of nearly every variety of girder had been canvassed in the Institution, he hoped it would not be deemed out of place, or hypercritical, to draw attention to some minutiæ of the construction of this bridge. The form of the upper member of the main girder might be compared to an inverted trough, but having, besides the external sides, two other longitudinal plates dividing the trough into three parts. The top of the trough was of considerable substance, but towards the ends of the girder, the external sides were each 2 feet deep and $\frac{3}{4}$ of an inch thick. The pins by which the diagonals were attached to the top of the girder, at intervals of 11 feet from centre to centre, and along the line of which the pressure was propagated from the ends to the middle, were, he thought, too low down; being, in effect, about 8 inches below the centre of gravity of the section of the trough. Wherever the object was to communicate pressure to any material acting in the nature of a column, it was important to carry that pressure along the line of the centre of gravity of the section; for if this precaution were neglected, flexure must take place. In the Newark Dyke bridge,[1] the upper, or compressed member, was made of cast iron, the strain being carried, as it ought always to be, through the axis of the column. Referring, now, to the Charing Cross Bridge, the sectional area of the iron at the middle of the second bay from the end of the girder was not so great, of course, as at the middle of the girder; but the pressure brought on there by the diagonals was greater in proportion than it was in the middle. If his calculations were correct, it would appear, supposing all the iron in the section to be compressed, square on, to the extent of 3 tons per square inch, that that pressure was increased, by flexure, to about 7 tons per square inch on the outside fibres at the lower edge of the trough. There was no point in the construction to which more attention ought to be paid, than this agreement of the line of strain with the neutral axis of the column; and where the intervals between the points of application of the compressing force were considerable, in the present case as much as 11 feet, in which there was room for the column to bend, the matter was very important. In the Britannia Bridge, where the area of the upper member was very great, the pressure was brought on by rivets every 4 inches, and though these were attached quite at the bottom, the radius of flexure could never be greater than that due to the whole deflection of the bridge. The case was very different where the pressure was brought on at wide intervals, and the wider these were, so much the more would be the importance of confining it to the axial line of the material. He would like to hear the opinions of other Engineers on this question, inasmuch as if he were correct in his assumption, that the strain might thus be increased from 3 tons up to 7 tons on the square inch, on any of the fibres of the material, it was evidently a consideration that could not be safely neglected.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xii., pp. 601–611, for "A Description of the Newark Dyke Bridge, on the Great Northern Railway," by J. Cubitt.

Mr. HEMANS said, he regarded this bridge as one of the most perfect pieces of ironwork of the kind ever produced. The great duty each individual cylinder had to perform, from their being so wide apart, and the great load they had to sustain, under the severe tests applied, showed that the work had been admirably put together. There was one part of the structure, however, which seemed to admit of criticism ;—that was, the mode of suspending the cross girders, by stirrup-irons, which he thought was not usual; nor did he observe, in the Paper, that the sectional area of the rivets attaching the stirrup-irons to the bottom girders was stated. As a matter of taste, the appearance of the structure would have been improved, if the bottom line of the bridge had been continuous, and the ends of the cross-girders had not been shown. Though there might be a difficulty in making a continuous line, in consequence of the projection for the formation of the footway, still means might be devised for uniting the ends of these girders, so as to present a continuous line. That mode of construction had been adopted in the little bridge over the ornamental water in the St. James's Park; but he thought the effect in that case was not good. He could not agree in the views which had been expressed, as to the position of the pins relative to the top and bottom webs, causing so much greater pressure; because the ultimate thrust and strain must come upon the top and bottom webs, and could not be taken as confined entirely to the line of the pins.

Mr. J. M. HEPPEL said, it has been truly stated, that no universal rule could be laid down for the adoption, under all circumstances, of either continuous or non-continuous girders. In India he had used the continuous girder, not only for the sake of economy of materials, but also for convenience of construction; because the effect of that plan was to save the necessity for providing staging, or scaffolding. The girders were constructed in continuous spans of two lengths each, so that each girder had three bearings,—one in the centre and two at the ends. These double-span girders were put together at one end of the bridge, and were then hauled over to their bearings on the piers. The rivers in India being subject to heavy periodical floods, the erection of staging was a difficult matter, and the plan alluded to had been found to be very advantageous. He imagined, in the present instance, with girders of such magnitude it might be attended with more difficulty. In the cases he referred to, the spans of the girders did not exceed 70 feet, or 80 feet. With regard to the observations of Mr. Phipps, he should have thought the deviation of thrust from the centre of resistance of the upper member, which might be considered in the nature of a column, was calculated to act prejudicially upon it; at the same time it was but fair to presume, that the designer of the bridge had kept that point in view, and would be able to show, that it had been designed throughout on the best principles.

Mr. JOHN COCHRANE said, it was a matter of some difficulty to give a verbal description of the drilling-machine, because, though simple in its action and effective, it was rather complicated in its parts. In consequence of the great number of plates in the top and bottom flanges, Mr. Hawkshaw decided, in order to secure accurate work, that the rivet-holes should be drilled, and not be punched out. For that purpose a machine was designed, which was capable of drilling all the holes through one series of plates, simultaneously, as it would have been too costly to have drilled each hole separately. The result was, that the cost of drilling was less than that of punching; and the cost of three of these machines was covered by the saving of labour which they effected. The main girders had a camber of 4 inches in the middle. This was not obtained in the ordinary way, by variation in the lengths of the diagonals, but by drilling the holes in the plates of the top flange with a pitch of 4 inches, and in the bottom with a pitch of 3·995 inches. Of course great mechanical accuracy was necessary to secure so small a variation, but when the girders were erected, the camber was perfect.

Mr. F. J. BRAMWELL remarked, that they owed a great deal to the President for having decided that the holes should be drilled, and to Messrs. Cochrane for designing the machinery which made it practicable in a commercial point of view. Nothing could be more barbarous than punching the holes. It was a process that destroyed the iron; it was, generally speaking, inaccurate; and it rendered uncertain what portion of the iron carried the strain. It could not be too generally known, that good workmanship was always the cheapest.

Mr. J. SCOTT RUSSELL, V.P., said, that before seeing this bridge, he had been in favour of that more simple process which approached nearer to ship-building and to ordinary girder-building; but the workmanship of this structure appeared to be more of the nature of fitted and finished engine work, and therefore likely to be on the whole more costly, than a simple lattice, or girder bridge. It did not, however, appear, from the actual prices given, which he hoped had been satisfactory to the contractors, that the cost of the bridge was greater than that of a lattice, or a girder bridge; while the workmanship was, in accuracy and precision, greatly superior to anything usually met with in such structures. The success of the plan for drilling rivet-holes had certainly been complete. The general design and organization of the work had enabled this accuracy to be attained; but unless a bridge was systematically designed, so as to admit of the easy application of this system, it might turn out to be dear and unsatisfactory. He should like to hear the reasons which had caused the principle of continuity in the girders not to be adopted to the full extent. He had so high a sense of the value of continuity, that unless the local difficulties were considerable, and the special advantages of an opposite course were very strong indeed, he should in all cases make such a bridge as this continuous. So far as he understood Mr. Phipps' remarks, he agreed with them in principle, he could not say in measure, because he had not made the necessary calculations. He quite felt that the pins which terminated the parallelogram were a great way from that part of the upper web which did sustain the strain, and that before the strain was conveyed to a sufficient quantity of that section, the pins themselves would undergo a strain nearly double that which the top of the girders would ultimately have to sustain as a mean of the whole. No doubt there was some explanation for that, and he only repeated his impression of the correctness of that statement, in order to elicit from Mr. Hawkshaw a full narration of all the circumstances. Possibly it might be said, that the parallelograms, as constructed, took off so much of the strain, that there remained only a comparatively small strain between point and point.

Mr. E. A. Cowper observed that if, as he imagined was the case, in the last bay there was a thick joint to receive the last pin; and that bay was stiffened, to a considerable extent, with plate, so that instead of the line of thrust being horizontal it might with safety be slightly inclined, there could be no objection to the construction. He should be glad to know how the proof weight of 400 tons, for one bay of 154 feet, had been arrived at. It was an excellent proof weight for a girder supporting two lines of rails, as it amounted to nearly 1⅓ ton per lineal foot on each line, and locomotives frequently weighed 1 ton per lineal foot, or even a little more. He thought all bridges ought to have ample strength to carry a crowd of people; and the public had a right to be informed, what proof weight was adopted, by the Government Inspectors, for proving common road bridges, such as those at Westminster and at Lambeth. He had tried the weight of a number of labourers, by weighing each man individually, and then by measuring the exact space they occupied when standing close together, as in a crowd, when he found their collective weight was fully 140 lbs. per square foot; therefore in designing bridges of large and small spans, he had taken 140 lbs. per square foot as the possible load. He was, however, aware that from 60 lbs. to 80 lbs. was often taken as a test load, but that was far below the weight of a crowd of able-bodied men.

Mr. R. MALLET remarked that, during the building of Buckingham Palace, Mr. Nash ascertained the greatest possible load of human beings that could be brought upon a given space, with reference to the so-called fire-proof floors of the Palace. Within a hoop, he thought of about 20 feet diameter, as many men were caused to stand as could be wedged into it, the last men being lowered down amongst the others. The result gave a load of 120 lbs. per square foot. The particulars of that experiment would be found in the blue-book relative to the floors of that Palace.

Mr. HAYTER stated, that 70 lbs. per square foot was probably the maximum living load that could be crowded on a given space. It was not important to determine this with accuracy, as regarded the Charing Cross Bridge, inasmuch as the side footpaths were the only public thoroughfares across it, and the load on these would be insignificant, when compared with the load that could come on the bridge, if the four lines of railway carried by it were weighted. He might, however, mention, that Messrs. Cochrane and Co. had tried an experiment, selecting for it the tallest and most muscular men in their establishment, and the result proved that the above estimate of 70 lbs. was ample.

In answer to the inquiry as to the amount of strain on the rivets by which the angle-irons carrying the cross girders were attached to the main girders, and also the amount of the strain on the rivets uniting the cross girders to these angle-irons, he would remark that this—which would be a direct shearing strain—would amount to about 3 tons per square inch. This would be the case, assuming a moving load of heavy locomotive engines packed closely together on the four lines of railway, and the footpaths simultaneously crowded with people—an excessive assumption, inasmuch as it was inconceivable that such an occurrence could ever happen by mere accident.

Mr. F. W. SHEILDS said that, with respect to placing the pins in the centre of the section of the top flange, all his experience convinced him, that such a construction, however plausible, was not calculated to obtain the best results from the iron. He believed that the greater part of the section should be at the top of the flange, where the strain was most severe, as in dealing with iron the object was to prevent the commencement of fracture. It was sufficient, therefore, in all such cases, to provide that the pin which attached the diagonal brace to the flange should have sufficient section of flange underneath it to prevent the pin from tearing away from the flange; and if that were done, the pin might be trusted with safety to distribute the compression along the length of the flange. It appeared that the amount of pressure, 8 tons per square foot, upon the clay bottom in the cylinders, was somewhat unusual. In his own practice, unless the clay was indurated so as to approach the nature of shale, he should hardly think of exceeding 4 or 5 tons per square foot. No doubt the results of the severe tests which had been applied to the Charing Cross Bridge were the best proof of its solidity. With regard to the workmanship of the girders, he could also bear his testimony, that he never saw so accurate and well-finished a piece of work of the kind.

Mr. HAWKSHAW,—President,—said, the weight that could be put upon London clay would depend upon the point where the weight was placed. All geologists knew, that if London clay was penetrated to a sufficient depth, it was capable of carrying a very great weight, much more, in fact, than he had put upon it, although the clay near its surface could not generally be loaded to that extent. With regard to the observations of Mr. Phipps, he agreed that it was desirable the pins should be, as nearly as possible, in the line of the centre of gravity, but practically, in all plate girders, it was difficult to do so. In the case of the Charing Cross Bridge, there must be room for the pins, which were 8 inches in diameter, and for the upper portion of the diagonal bars, which were large forgings. Care was taken to provide sufficient strength in the web, through which the pins passed, to avoid mischief.

With reference to the loading of the cylinders, the first two were tested with 700 tons each, and the others with 400 tons each; the greater load was not continued, as it was a tedious, and rather dangerous, process to build up a solid cube of rails 22 feet square, upon cylinders 10 feet diameter, before any stays were attached to them; and it required careful balancing to make the experiment. In applying the load of 700 tons upon the cylinders, as it was necessary to prevent the weight bearing on the castings, spruce deal planks, 3 inches in thickness, and having together a diameter of rather less than 9 feet, were laid upon the top of the brickwork in the cylinder. The upper surface of these planks was about 2 inches above the edge of the cylinders, and on this surface a thin stratum of cement, nowhere exceeding 1 inch in thickness, was carefully laid, to receive first flat-bottomed iron rails, and then other rails laid crossways, and so on, until the cube of 22 feet was built up. When the rails were taken off, there was not the slightest crack in the cement, and the spruce deals looked as if they had not carried any weight. He was surprised to find so thin a layer of cement, placed on an irregular surface of wood, carrying so great a weight, without a trace of the work it had performed. He gave up the continuity in the construction of the girders with some reluctance. At one time it was thought that the girders might be constructed singly, and be lifted into their places. Then, in order to carry out the system of drilling, instead of punching, the plates, he was desirous of simplifying the plates as much as possible. The whole bridge consisted of a repetition of a few forms; two sizes of plates, with a given number of holes in each, being all that was required for a large portion of the structure. By means of the ingenious machine designed by Messrs. Cochrane, for drilling the plates, much better and stronger work had been obtained. The drilling was executed with very remarkable accuracy. He saw plates of the same description piled one upon another for a height of 6 feet, and the accuracy of the drilling was such, that on putting the finger into the holes, or looking down them, they appeared nearly as smooth as the inside of a gun-barrel.

As to the appearance of the ends of the suspended cross girders being objectionable, when the footway was completed that defect would be removed, as the ends would then be hidden from view. He had been found fault with for assuming so much as 80 lbs. per square foot, as the weight of a crowd of human beings. French engineers, and others, were said to be content with 50 lbs. to 60 lbs. per square foot: but he was satisfied with 80 lbs. per square foot,—not that it had much to do with his calculation, because the test on this bridge would be chiefly locomotives. He was bound to say that the work had been executed by Messrs. Cochrane in a very accurate and creditable manner.

Mr. J. SCOTT RUSSELL, V.P., remarked that in the bow and string bridge erected over the new street at Southwark, for the Charing Cross Railway, the top and bottom members were similar to those of the parallel girder bridge over the Thames at Hungerford; but in the former case the points of support of the diagonals were even farther away from the centre of gravity of the cross section at the top, than in the Charing Cross Bridge; so that the defect pointed out by Mr. Phipps, if it really was a defect, was carried to a greater extent in that structure. However, in the bow and string bridge, the uprights and the diagonals had much less to do; indeed, from the ends being filled up solid, he thought the Engineer intended that the work should be done by the top and the bottom members, the diagonals merely keeping the truss in shape. If that were so, no doubt the construction was right; and in this case, with proper proportions, the work would undoubtedly be duly performed. Now, in the case of the Charing Cross Bridge, the top and the bottom members each consisted of a three-sided box, one of the three sides of each being composed of a large mass of plates, the uprights and the diagonals being at a considerable distance from the centre of gravity of the cross section of the top and bottom members, and the truss being filled up solid at both ends. Therefore, what had, in his opinion, to be determined, was the share of the work which the uprights and the diagonals took. If these were expected to bear a great part of the burden of the work, then he could agree with Mr. Phipps, that the points were too far removed from the centre of gravity of the top and bottom webs, and therefore from their work, and that a heavy strain would come upon them. If, on the contrary, the top and bottom were so firmly fastened, as in this case, that they might be depended upon to do the major part of the work, then the diagonals and the uprights were mere stays to keep the truss in form, and the evil likely to arise from the displacement, so to speak, of the centres of action, was not great; and Mr. Sheilds would, under such circumstances, be perfectly right in saying, that the points of attachment should be kept from interrupting the continuity of the top member, and that it would be preferable to cut the flanges at some distance from the centre of gravity of the cross section, than in any way to interfere with their continuity.

Mr. Phipps thought the question he had raised was of sufficient importance to justify a closer examination; especially as the opinion seemed to be entertained by some Members, that although his theory might be correct, yet very little effect would be produced upon the bridge from the cause referred to. For the sake of brevity, his remarks would be limited to the upper, or compressed, member of the girder, although it was obvious that similar reasoning would apply equally well to the lower, or extended, member. The effect on the former, however, was well understood to be the more detrimental of the two. The calculations applied to the upper part of the girder, in the second bay from the end, at A B, Fig. 1, page 536. With a distributed load of 700 tons on one girder, including the weight of the girder itself, the pressure on the upper member in the first bay would be 175 tons, and in the second bay 475 tons, leaving 300 tons of pressure to be brought on to the intervening pin by means of the diagonals. It was not easy to determine at what height above the centre of the pin this pressure of 175 tons was transmitted from the first bay to the second; but he had assumed it as being very near to the top part of the compressed member, which he had reason to believe was not far from correct. With these data, the resultant of the pressure at A, of 175 tons, and at B, of 300 tons, was 475 tons at C, Fig. 2, a point situated 3·6 inches below the line of the centre

Fig I.

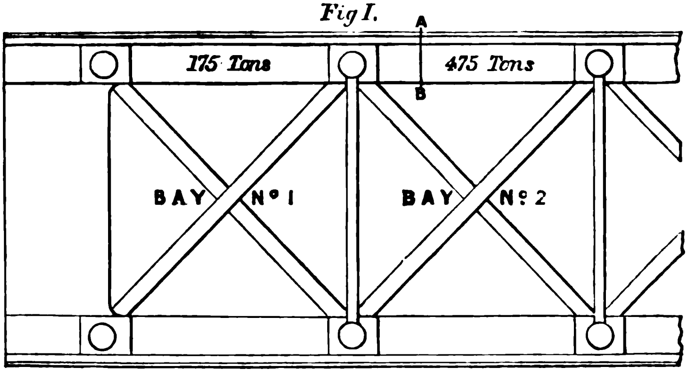

A
175 Tons
475 Tons
B
BAY N° 1
BAY N° 2

Fig. 3.

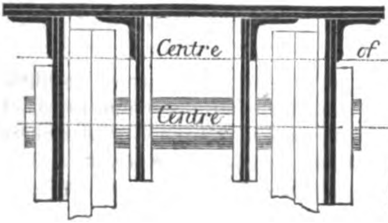

Centre
of
Centre

Fig. 2.

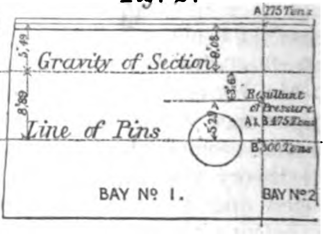

A 275 Tons
Gravity of Section
5.49
8.08
8.89
3.61
Resultant of Pressure
A & B 475 Tons
Line of Pins
5.28
B 300 Tons
BAY N° 1.
BAY N° 2

Fig. 4.

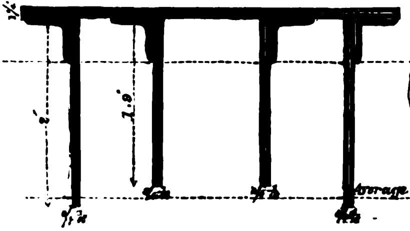
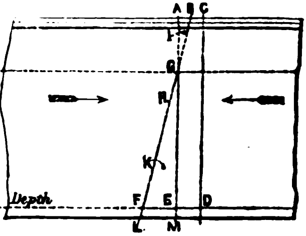

1¼"
2'
1.9'
Average

Fig. 5.


A
B
C
I
G
H
K
Depth
F
E
D
L
M

of gravity of the section. Fig. 5 exhibited the manner in which this force of 475 tons operated to produce detrimental pressure on the outer fibre of the iron at M. The method of ascertaining this had occurred to him two years ago, when studying the strains upon iron arches, in cases where the curve of equilibrium had travelled away from the line of the centre of gravity. It depended upon this axiom, that whenever a prism of any elastic material was compressed by a force on some line not corresponding with its centre of gravity, flexure must take place, and that to such an extent as would remove the centre of resistance from its original situation until it was perpendicular beneath the force applied. Now, the force of compression on the prism, when applied over the centre of gravity of section G, Fig. 5, might be represented by the content of the solid intercepted between two parallel planes A E and C D. If the compressive force be removed from G to H, in the line of the arrows, the flexure which would ensue might be represented by a certain amount of angular motion of the plane A G M, around the centre of gravity G. By a property of the centre of gravity, any angular movement around G would generate solids of equal magnitude, G A B and G E F, on contrary sides of the centre, and these represented equal forces. Now if I, and K, were the centres of gravity of these solids, then, in order that the point H should become the centre of gravity of the solid F B C D, the solid A C D E into G H must be equal to (G A B × G I) + (G E F × G K). When this condition was fulfilled flexure would cease, and H would be the true centre of resistance directly opposed to the compressive force. If E D be laid down from any scale of equal parts, as equal to the pressure in tons on the square inch, then L M would represent the additional pressure brought on the outside fibre of the iron, on account of the flexure, and A B would represent the diminution of pressure on the uppermost fibre.

Applying this to the Charing Cross Bridge, and calling—

a = the area of the whole section of the girder . . . . = 161·25 square inches.
b = the total pressure . . . = 475 tons.
c = the pressure on the square inch . = 2·94 „
d = the solid A C D E = $a \times c$ . . = 475 „
e = the solid G A B.
f = the solid G E F.
G H . . . . = 3·6 inches.
I K . . . . = 16·37 „
G E = the average depth below G . = 17·75 „
G M = the full depth below G . . = 19·25 „
t = the aggregate thickness of the four vertical plates . . = 3·25 „

$$\text{Then } f = \frac{d \times \text{G H}}{\text{I K}} = \frac{475 \times 3{\cdot}6}{16{\cdot}37} = 104 \cdot 4,$$

and in consequence of G E F being a triangle

$$\text{F E} = \frac{104{\cdot}4}{\text{G E} \times \frac{t}{2}} = \frac{104{\cdot}4}{17{\cdot}75 \times 1{\cdot}62} = 3 \cdot 63.$$

$$\text{L M} = \text{F E} \times 1{\cdot}08 = 3{\cdot}63 \times 1{\cdot}08 = 3 \cdot 92.$$

$$\text{A B} = \frac{\text{L M}}{3 \cdot 2} = \frac{3 \cdot 92}{3 \cdot 2} = 1 \cdot 2.$$

Thus, then, the square on pressure = E D = 2·94 tons on the inch.

The pressure on the bottom fibre = E D + L M = 2·94 + 3·92 = 6·86 tons on the inch.

The pressure on the upper fibre = A C − A B = 2·94 − 1·2 = 1·74 ton on the inch.

Mr. HAWKSHAW,—President,—thought that Mr. Phipps' observations on the Charing Cross Bridge were sound. It was clear that the diagonal strain on that bridge must be transmitted from one pin to another, along the top and bottom members of the bridge; and the nearer those strains passed along the line of the centre of gravity of those members the better. He did not however agree, that in boiler-plate bridges this desideratum was secured by the closeness of the rivets which connected the sides to the top and bottom. He believed the objection applied with more force to many of those bridges than to the Charing Cross Bridge. The girders of the Charing Cross Bridge were so designed, that the diagonal strain at the ends of the girders, if passed from pin to pin, through the vertical webs only, could produce no injurious effect, for the vertical webs at those points were made very strong; and the diagonal strains at the centre of the bridge were so small, that the vertical webs at that point also were stronger than necessary for the mere transmission of the vertical strains. Mr. Scott Russell had, in discussing this point, compared the Charing Cross Bridge with another bridge which was being erected over the new street in Southwark. But that bridge was constructed on totally different principles. It was in fact an arch, and Mr. Phipps' observations could not apply to it. It followed the same laws as any other arch, the weight being merely suspended from, instead of being placed upon, it. The bottom web was substituted for fixed abutments, and it also served to stiffen the roadway and to distribute the load. In that bridge the diagonal braces might be taken away, and still the bridge would stand. They were, however, of use in assisting to distribute the load, and to provide, to some extent, against flexure in the arch. For with loads unequally distributed, all iron arches were subject to flexure. This accounted for the small strain per ton which, it had been observed, was usually placed upon iron arches. If those arches could always be uniformly loaded, the whole would be put in compression; but light malleable and cast-iron arches, with heavy rolling loads, were subject to compression in some parts, and to extension in other parts; and thus it happened that a considerable portion of the cast-iron arches usually erected were not always available in resisting compression, and hence frequently not more than 1½ ton to the square inch, having regard to their whole sectional area, was placed upon them. In some cast-iron bridges subjected to the rolling load of a railway, probably not one-half the section of the rib would be brought into compression.

May 5, 1863.

JOHN HAWKSHAW, President,
in the Chair.

The following Candidates were balloted for, and duly elected:—JOHN BLOUNT and Captain VIRIATO DE MEDEIROS, as Members; EDWARD APPLETON, Captain FRANCIS JOHN BOLTON, and ROBERT TREFUSIS MALLET, as Associates.

No. 1,091.—"American Iron Bridges." By ZERAH COLBURN.

IN the United States, the first cost of the truss, or 'superstructure,' of a timber bridge of any given span is generally less than one half that of an iron bridge of the same strength. This fact will account for timber bridges having been so largely adopted in America. Iron was occasionally employed there as long ago as 1835, but it is only within the last ten or twelve years, that it has been used to any considerable extent. At the present time, it is generally admitted by American Engineers, that the original cheapness of timber structures does not compensate for their rapid decay, their frequent destruction by fire, and the constant repairs and watching which they demand.

Among the earliest iron bridges erected in that country were a few cast iron tubular arches, including one of 80 feet span. The design of these was due to Major Delafield, of the United States Engineers, who adopted them at about the time when somewhat similar arches were employed in France, by the late M. Polonceau, in the construction of the Pont du Carrousel, over the Seine. Major Delafield's arched ribs were elliptical in section, the transverse vertical axis being about four times the length of the conjugate axis. In 1858, an aqueduct bridge was erected at Washington by Captain Meigs, of the United States Engineers, who used for this work two arched ribs formed of water-pipes, through which the water flows, the pipes being circular in section, as that form encloses the greatest quantity of water with the least amount of iron. (Plate 20, Fig. 1.) The span of this bridge is 200 feet, the rise being 20 feet; and the width of the bridge over all is 28 feet. The pipes are 4 feet in diameter inside, and 1½ inch thick. They are lined with staves of resinous pine, 3 inches thick, to prevent the freezing of the water. The pipes are not cast to the curve of the arch, but are in straight lengths of about 12 feet, with flanged joints, faced in planes parallel to the corresponding radii of the arch. At the skewbacks, the ends of the pipes are faced to large conical bases admitting the water, and resting upon the masonry. There is no allowance for expansion, or contraction. The roadway is of timber, supported on spandrils formed of rolled wrought iron beams 9 inches deep, and weighing 90 lbs. per yard. The bridge was tested with the arched ribs filled with water, and with a load of 125 lbs. per square foot upon the roadway. The weight of each arched rib, when filled with water, is about 160 tons; that of the spandrils of each rib and of one-half of the roadway is about 30 tons; while the test load was equal to about 160 tons on each half of the roadway, making the whole weight about 350 tons on each rib. The thrust of one-half of this weight upon each abutment would be about 470 tons, and as there are 238½ square inches of sectional area of iron in the pipes, this would correspond to a strain of about 2 tons per square inch. This strain, while it includes that due to the weight of the water in the pipes, is exclusive of that due to its pressure. The pipes were proved to a pressure of 300 lbs. per square inch.

Major Delafield's and Captain Meigs' bridges are, so far as the Author is aware, the only iron arches yet completed in the United States; unless the application, in 1849, of a light cast iron arch to each side of a timber truss, of 133 feet span, on the Pennsylvania Central Railroad, may be regarded as another instance. A roadway bridge, with two cast iron arched spans of 185 feet each, to cross the Schuylkill River at Philadelphia, had been designed by Mr. Strickland Kneass, C.E., and was about being let to contract when the Author was last in America. The rise of these arches was to be 20 feet, and the whole width of the roadway and of the footways 42 feet. Each arch was to be formed of seven ribs segmental to a circle of 224 feet radius, and of a uniform depth of 3 feet 6 inches; the top and bottom flanges were to be 8 inches wide and 3 inches thick, the web 2½ inches thick, and the whole sectional area of each rib 138 square inches. The thrust at the skewback of each rib, including that caused by the weight of he spandrils, cast iron floor-plates, 6 inches of gravel, a granite paving, and a load of 70 lbs. per square foot of the roadway, will be 217 tons, equal to 1·63 ton per square inch of the section of the rib. In addition to diagonal bracing of cruciform section, the ribs are to be tied together at fourteen points in their length, by round wrought iron rods, enclosed in cast iron distance pieces. The spandrils are to be upright posts, 4 feet apart from centre to centre, cruciform in section, and having each 28½ square inches of cross sectional area. Some ornament is contemplated upon the bridge, but the violation of symmetry, involved in the adoption of an even number of arches, would alone prevent its consideration as a work of art.

But few simple, or compound cast iron girders are in use as bridges in America; and the instances already given include, it is believed, nearly all the cast iron bridges in that country, with the exception of a few cast iron pivot bridges, and perhaps one, or two ornamental bridges in the Central Park at New York. Long accustomed to trussed timber bridges, American Engineers, in adopting iron, naturally employed it in trusses also; and, with the exception of the tubular and plate girder bridges erected under the direction of English Engineers in Canada, there are but a small number of plate iron bridges in America. The first was constructed in 1846, and was erected in place of an old timber bridge in 1847, by Mr. James Millholland, then the Engineer to the Baltimore and Susquehanna (now the Northern Central) Railroad. This was 50 feet span, and the girders were each formed of two sides of plates $\frac{1}{4}$ inch thick and 6 feet in depth, a balk of timber 12 inches square being bolted, as a compression member, between the sides at the top, which was further stiffened by two wrought-iron bars, 5 inches deep and $\frac{3}{4}$ inch thick; while four bars, each 5 inches by $\frac{3}{4}$ inch, were riveted along the bottom of each girder. The sides of each girder were stiffened by stay-bolts $\frac{5}{8}$ inch diameter, enclosed in cast iron distance pieces, and 12 inches apart from centre to centre. The centre of each girder was placed exactly under the rails, which were spiked to the timber forming the compression member of the girder. The breaking strength of the pair of girders would be equal to about 250 tons of distributed load, the weight of the bridge being 14 tons. When completed, this bridge was coupled at each end to a railway waggon; a temporary timber truss, resting through transomes upon the waggons, being erected over the bridge, which was then raised clear of the ground, and slung by chains to the truss. (Plate 20, Fig. 2.) A locomotive was next attached, and the bridge was thus taken 19 miles down the line, from Baltimore to a stream known as Carroll's Run. The plate girder bridge was run exactly over the place it was intended to occupy, the wheels of the waggons were blocked, and some large screws were set up, to lower the bridge from the trussing by which it was supported. The existing timber bridge was then cut away into the stream below, and the girder bridge was lowered into place with the permanent way ready for traffic. The temporary trussing was next taken apart and piled upon the waggons, the engine crossing the bridge to pick up one of them, and then returning home; the whole interruption to the traffic not exceeding two hours. Mr. Millholland afterwards erected a bridge of similar construction for ordinary street traffic in the city of Baltimore. This latter bridge had four girders, 85 feet long, only 4 feet deep at the centre, and 3 feet deep at the ends. Mr. Herman Haupt, C.E., subsequently erected several boiler-plate bridges, of somewhat different construction, upon the Pennsylvania Central Railroad.

Before describing the various forms of iron truss bridges adopted by American Engineers, it is proper to give some information as to the strength of American iron. Exact data upon this point cannot easily be obtained; for, unfortunately, the practice of imposing a test of breaking strength, upon the iron supplied by contractors for large structures, has not been adopted in the United States. The Government there have, however, for many years caused careful experiments to be made upon the iron employed for, and upon samples cut from, guns cast for the coast and naval defences. The iron employed generally has a tensile strength of from 5 tons to 6½ tons per square inch in the crude state, or pig-iron. On melting this iron, however, it is kept for some time in fusion, and the first castings generally have a tensile strength of about 9 tons per square inch. For guns, the iron is now always re-melted, sometimes for the third or fourth time; and at each melting it is retained for from one to three hours in a state of fusion before being poured. This is done in an air-furnace, or, in other words, a furnace in which the fuel is burnt on a separate grate, and only the natural draught is employed. By this treatment the iron is decarbonised to a considerable extent, and its toughness is greatly increased. Iron of the second melting often has a tensile strength of 13 tons, and that of the third melting of 15½ tons. These may be given as about the mean of a number of experiments made by Major Wade of the United States Ordnance Board, and published, in 1856, in a quarto volume entitled "Reports of Experiments on the Strength and other properties of Metals for Cannon. With a description of the Machines for testing Metals, and of the Classification of Cannon in Service." The strongest cast iron tested by Major Wade had the great tensile strength of 20½ tons; samples cut from one hundred gun-heads had a mean tensile strength of 14·9 tons; a large number of proof bars in another case had a mean strength of 16·23 tons; and in the case of a 10 inch gun, cast hollow, upon Lieutenant Rodman's process, the mean tensile strength of thirty-eight samples was 16·875 tons, the strongest sample having a strength of 19·83 tons, and the weakest 15·275 tons. In another case, the mean strength of fourteen pigs of iron in the crude state was 5·66 tons, while that of twenty-seven guns cast from these pigs and others from the same furnace was 15·75 tons, the guns having been cast only after the metal had been three times melted, and kept in fusion from one to three hours at each melting. There appears to be but little iron in any American cast guns of a less tensile strength than 11 tons per square inch; and in 1851, the Author himself saw portions cut from 11-inch guns, weighing 6 tons 15 cwt., tested up to 16·14 tons. Major Wade also tested the transverse strength of a large number of gun irons. The trials were made upon bars 2 feet long and 2 inches square, supported on knife edges 20 inches apart. The results may, however, be reduced to the standard to which English Engineers are most accustomed, that of a bar 2 inches deep and 1 inch wide, resting on supports 3 feet apart. Thus reduced, the transverse breaking strength of a large number of samples of re-melted iron, made from pigs cast at five different furnaces, varied from 27¾ cwt. to 48·1 cwt., the general strength of the samples being 34 cwt. Major Wade also gives the crushing strength of the irons upon which he experimented, the minimum being 37¾ tons, and the maximum 77¾ tons. It should be observed that, by re-melting and protracted fusion, the specific gravity of the iron is raised from 6·9 in some cases to 7·4, or from a weight of 430½ lbs. up to 461¾ lbs. per cubic foot. A Committee of the Franklin Institute made a series of experiments twenty-five years ago, from which it appeared, that the mean tensile strength of a large number of specimens of cast iron poured at the first melting was 9⅓ tons; and the iron employed by the Philadelphian Engineers now bears from 7·14 tons to 10·2 tons. Mr. Albert Fink, C.E., in testing the iron employed, in 1858, in the construction of a large bridge, on the line of the Louisville and Nashville Railroad, adopted bars of the sizes upon which Mr. Fairbairn had experimented, viz., 5 feet long and 1 inch square, placed on supports 4 feet 6 inches apart. Mr. Fink adopted, as his minimum transverse breaking weight, a load of 550 lbs. in the centre. From a published statement which he afterwards made of the results, it appeared that the mean breaking weight was 610 lbs., and the highest 728 lbs. Reduced to bars 2 inches deep and 1 inch wide, placed on supports 3 feet apart, the minimum breaking weight was 29½ cwt., the mean 32·68 cwt., and the highest 39 cwt. This iron was a mixture of two-fifths cold blast, two-fifths hot blast, and one-fifth scrap. Without the scrap, Mr. Fink says his bars would bear but 500 lbs., equal to 26·8 cwt., when reduced to the standard already referred to.

Of wrought iron, the experiments made by the United States Board of Ordnance gave a tensile strength ranging, with different specimens, from 17 tons to 33·3 tons per square inch. Experiments made twenty-five years ago, by a Committee of the Franklin Institute, gave a mean strength of about 26 tons for plate iron. At the present time 27 tons is generally expected of American boiler plate. Mr. Roebling, in his last Report to the Directors of the International Bridge Company, for whom he designed and constructed the Niagara Suspension Bridge, details some experiments upon cold blast charcoal iron, the ultimate strength of which he gave as from 31¼ tons to 35·71 tons per square inch. Bars of this iron, after lying in a winter's night at a temperature hardly above zero of Fahrenheit, were suddenly put under a strain of 20½ tons per square inch, with which there was no visible stretching. They were then struck violently with a heavy iron bolt, and only broke after a considerable number of blows. Professor Walter R. Johnson, by whom most of the Franklin Institute experiments were conducted, has tested iron bars, from the Lake Superior district, to the extraordinary tensile strength of 39·99 tons. In the year 1859, Mr. Albert Fink tested three bars of iron which had been in use for between seven and nine years, under full loads as tension bars in some of his bridges on the Baltimore and Ohio Railroad. One bar, 14 feet 6 inches long and 2 inches by ¾ inch, bore 30·61 tons per square inch; another bar, 12 feet 8 inches long, and 1·46 inch by 0·6 inch, bore 30·28 tons per square inch; and a third bar, 13 feet long and 1·62 inch in diameter, broke at a weld with 24⅞ tons per square inch. All these bars, it is to be remembered, had for an average of eight years been subjected to repeated strains of about 5½ tons per square inch, in addition to the effects of severe frosts, vibrations, &c. Mr. Roebling, a few years ago, removed 30 tons of hammered charcoal bars from the old Monongahela Bridge at Pittsburgh, and notwithstanding that they had been in severe service for thirty years, he reported that every bar would bear a strain of nearly 27 tons per square inch, or, in round numbers, 60,000 lbs. This strength was ascertained also in the case of the plates of locomotive boilers, after thirteen years' work, on the Baltimore and Ohio Railroad. From what has been stated it will be seen, that American Engineers may work up to rather higher strains than are commonly allowed in this country. The qualities of the best American iron—known here to some extent through the Acadian iron, which, although made in Nova Scotia, is of the same quality as the best class of cold blast charcoal iron made in many parts of the States—are due to the purity of the ore and of the fuel employed in the manufacture. The hot blast anthracite iron, largely made in the Eastern States, is also strong and of good working quality.

On the first adoption of iron for railway bridges, American Engineers permitted high working strains. One bridge of 66 feet span, which broke down in the summer of 1850, on the New York and Erie Railroad, had but 12 square inches of cast iron in the top chord, and but 4 square inches of wrought iron, weakened by bolt holes, in the bottom chord, of each truss for a single line. The ordinary working strain was found to be about 13·4 tons per square inch of the wrought iron. The best present practice in America is, however, to work the iron to as low, if not a lower strain than is allowed even in England; or, in bridges of less than 150 feet span, to a tension of 8,000 lbs., or 3·57 tons per square inch of wrought iron, and a compression of 10,000 lbs. or 4·46 tons per square inch of cast iron. Even these moderate strains occur only under a load of 3,000 lbs., or 1·34 ton per lineal foot of a single line bridge. This load is estimated to be made up as follows:—A span of 150 feet is assumed to be covered by two first-class locomotives with a snow plough attached, the latter weighing about 15 tons, and with two and a half eight-wheel loaded goods waggons, the whole weighing 108 tons, or 1,600 lbs. per running foot. To this is added an estimate of the weight of saturated snow, equal to 6 inches in depth of water, or 30 lbs. per square foot over the whole floor of the bridge. The pressure of a high wind against the bridge and the train upon it is furthermore estimated at 30 lbs. per square foot, and resolved into a vertical strain of nearly 600 lbs. per lineal foot; and a further allowance of 200lbs. per lineal foot is then made, upon the supposition that the breaks upon the tenders and goods waggons are all applied while the train is in motion, thus throwing a strain upon the chords of the bridge.

Of the iron trussed bridges about to be described, all have, in common, certain peculiarities distinguishing them from the trussed structures adopted in this country. In almost every case the compression members of American iron trussed bridges are of cast iron cylindrical or octagonal pipes. These simply abut, end to end, against each other; and although means are employed to prevent lateral motion of the ends, flanges and bolts are never introduced for that purpose. Another, and one of the most important peculiarities is the depth of truss employed, a depth which is seldom adopted by English Engineers, except in a few instances, as at Chepstow and at Londonderry. American Engineers consider a depth of one-eighth, for spans of 200 feet, as only moderately deep; for shorter spans depths of one-seventh and one-sixth are common; and in the case of one bridge of 120 feet clear span, the depth from the centre of the top to the centre of the bottom chords is 23 feet, a proportion of nearly one-fifth the span. It should, however, be observed that, in some of the American trusses, the arrangement of the tension members is such that, if the depth of truss were not considerable, the diagonals would be inclined at hardly more than 8° or 10° from a horizontal line, in which case a very large quantity of material would be employed in proportion to the supporting power obtained. No American iron, or timber bridge is ballasted. With the exception of a plank footpath, the floor is, indeed, very often left quite open, or more correctly speaking, the bridge has no floor. In the case of bridges having the rails at, or above, the level of the top chords, known in the States as 'deck bridges,' parapets of any kind are seldom employed. The trusses are often placed at so short a distance apart, in the case of deck bridges, that the carriages actually overhang the sides, and a passenger on looking out of a window, is unable to discover any support beneath the train. In no bridges of two or more spans erected in the States are the trusses made continuous over a pier, each span being always treated as a bridge by itself.

One of the earliest iron trusses adopted in the States was a trellis known as Rider's bridge. Cast iron T or angle irons were employed in compression, and wrought iron bars in tension. These bridges were so slightly proportioned, that they occasionally broke down, and the Author is not aware that the plan is now adopted in new structures.

The Whipple Bridge was introduced by Mr. Syrene Whipple, C.E., in 1848, and has since been improved in detail by Mr. J. W. Murphy, C.E. Drawings are exhibited of one of these bridges of 125 feet span, with the railway supported on the lower chords (Plate 20, Fig. 3), and of another of 86 feet span, with the railway on the top. (Plate 20, Fig. 4.) These spans are measured from centre to centre of the bearings on the abutments, the clear spans between the masonry being 120 feet and 80 feet respectively. Referring to the 125 feet span, for a double line, there are three parallel trusses, the outer trusses being each 14 feet from the middle truss, measuring from centre to centre. Although the middle truss may possibly have to bear an occasional load equal to that on both the other trusses, its strength is only about one-half greater than that of either of the outer trusses. The depth of the trusses, from the centre of the top to the centre of the bottom chords, is 23 feet, or 0·184 of the span. The top chord is formed of cylindrical cast iron pipes, all of which are 8 inches in external diameter. At the centre of the middle truss these are $1\frac{1}{4}$ inch thick, giving $26\frac{1}{2}$ square inches of section; at the centre of the outer trusses they are 1 inch thick, giving 22 square inches of section; and at the ends of both trusses, they are $\frac{3}{4}$ inch thick, giving 17 square inches of section. The leaning end columns are 8 inches in external diameter at the ends, 9 inches at the centre, and $\frac{3}{4}$ inch thick, and are stiffened to some extent by mouldings. The bottom chord of each truss is formed by a chain of square bars, 10 feet 5 inches long between the centres of the eyes. At the centre of the middle truss there are four of these bars, $2\frac{7}{8}$ inches square, giving 33 square inches, and at the ends two bars $2\frac{1}{8}$ inches square, giving 9 square inches. The outer trusses have four bars, $2\frac{1}{2}$ inches square at the centre of each bottom chord, equal to 25 square inches, and two bars 1⅞ inch square at the ends, equal to 7 square inches. The upright cast iron posts are all 6 inches in external diameter, and ⅝ inch thick, each post being made in two lengths, faced at the ends, and abutting on each other, with a truss of four round rods 1¼ inch in diameter, to prevent lateral failure. The diagonals are in pairs of square rods, those at the ends of the middle truss being 2⅛ inches square, and at the centre 1⅞ inch square. In each outer truss there are two diagonal tension bars at the ends, each 1⅞ inch square, the two at the centre being 1⅜ inch square. The diagonals are formed also as eye-bars, and grasp pins 2½ inches diameter in the top chord, and others 3½ inches diameter where the links, or bars of the bottom chord are connected. The upright posts bear also upon these latter pins; and in the top chord the pins, passing transversely through the joint where the cylindrical pipes abut upon each other, also serve the purpose of preventing lateral failure, no other means being employed to keep the separate pipes of the top chord in line. The diagonal tension bars only cross each other in two panels on each side of the centre of the truss. The bars which are carried past the centre are 'counter rods;' they are of light section, and have slots and keys at their lower ends, for adjusting their length to any required camber of the truss. They assist also, to a certain extent, in the transmission of the strains due to unequally distributed loads. The top and bottom chords are respectively braced horizontally with transverse and diagonal bars. The railway bars are supported upon longitudinal timbers, which rest at every 10 feet 5 inches, upon a pair of transverse wrought iron rolled beams, each 9 inches deep, and weighing 90 lbs. per yard. The ends of these beams rest upon cast iron blocks forming the bases of the upright posts. The height or headway, from the top of the rails to the under side of the top bracing, is 19 feet 6 inches. The ends of the truss are not supported on rollers, the bottoms of the leaning end columns resting directly on the masonry. The weight of the three trusses, with the horizontal top and bottom bracing, but exclusive of the floor beams and longitudinal timbers for supporting the rails, is 73½ tons, or nearly 6 cwt. per foot of single line. Of this weight, 43 tons are cast, and 30½ tons wrought iron. Of the whole weight of the three trusses, about 32 tons, or 43 per cent., are in the upright posts and their truss rods, and in the leaning end columns and the vertical and diagonal tension rods. The rolled floor beams for the double line weigh 9 tons, the longitudinal timbers about 14 tons, and the rails and fastenings 6 tons, making a total weight for the double line of 102½ tons, equal to a little more than 8 cwt. per foot of single line. With an additional distributed load of 3,000 lbs. per running foot on each line, the tensile strain at the middle tension rods of the middle truss would be 4·27 tons per square inch, and in the outer trusses 3·12 tons per square inch. The compressive strains in the top chords would be respectively 5·32 tons per square inch in the middle truss, and 3·55 tons in the outer trusses. These strengths, calculated for the maximum load on both lines, are not carried out in every part of the bridge; but with a train on a single line, no part is strained in tension beyond 8,000 lbs. per square inch, nor in compression beyond 10,000 lbs., and the ordinary working strain does not exceed 2½ tons per square inch in tension, nor 3 tons per square inch in compression.

In the construction of the bridges just described, the tension rods are rolled in entire lengths, without weld, and from iron of the kind employed for railway carriage axles of good quality. The bars are rolled square, because that form comes out of the rolls best, when bars of unusual length are required. The eyes of all the tension rods are formed by bending the full size of the bar around a pin, the end overlapping the bar for 12 inches, and being closed by a long scarf weld. At the eyes, therefore, there is twice the section of iron that is allowed throughout the rest of the bar. The eyes are truly bored out, the pins are turned, and all the flat bearing surfaces are faced in a lathe. Bridges of this construction, up to spans of 165 feet, possess as much stability as timber trussed bridges; and the deflection of one of these bridges, of 165 feet span, on the Lehigh Valley Railroad, under a goods train of full weight was only three-quarters of an inch.

The cost of American bridges, of all kinds, is always estimated at so much per lineal foot. For a single line railway bridge, of 165 feet span, of the construction already described, the cast iron would weigh about 6 cwt. per lineal foot, and the wrought iron, including floor beams, as much more, making 12 cwt. per foot. The cost of pig iron is usually £4 10*s.* per ton, and castings in considerable quantities £10 per ton. Wrought iron of the extra quality employed costs £23 per ton in the bar, being usually quoted at 2½*d.* per pound At these high prices of materials, bridges containing equal weights of cast and wrought iron are sold at about £25 10*s.* per ton in the builder's yard, although this sometimes covers the whole cost of the work erected in place. These prices, it is to be understood, are those which prevailed before the suspension of specie payments.

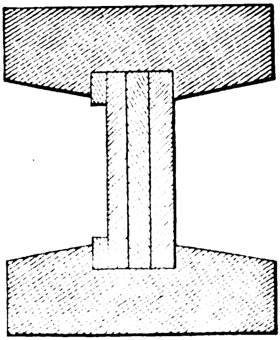
In 1861, an iron bridge was erected on the line of the Pennsylvania Central Railroad, across the Schuylkill river at Philadelphia. It had two clear spans of 192 feet each, and one pivot span, or turning bridge, 192 feet long. The construction was much like that already described as Whipple's. The truss, however, was only 19 feet deep, giving a proportion of depth to span of rather less than one-tenth. The upright posts, or struts, were formed of wrought iron, so rolled that two bars, when put together, formed an octagonal tube. The top and bottom chords of the turning bridge were formed of wrought iron rolled beams, so that either might resist extension or compression, according as to whether the span was turned on, or off, the line of the bridge. The three spans for a single line contained an average of 5 cwt. of wrought iron, and 7½ cwt. of cast iron per lineal foot. The bridge was constructed and erected by the Pennsylvania Railroad Company, and its nett cost, exclusive of masonry, was as follows:—

	£.	s.
145 tons wrought iron at £22 15s. 6d.	3,303	0
214 „ cast iron „ £6 11 3	1,404	0
Workmen in shops	1,442	0
Timber	127	0
False work and raising	842	0
Pivot of turning bridge	592	0
Painting	270	0
Engineering	131	0
Incidental expenses	33	10
Total	£8,144	10

The average cost was thus £22 13s. 6d. per ton, and about £14 4s. per lineal foot. The price of the cast iron is the mean of the prices of all the cast iron purchased, whether in the pig, or in castings from the founder's.

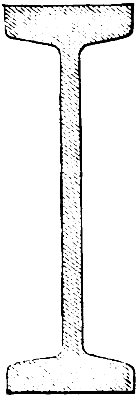
While referring to the wrought iron rolled beams employed for the top and bottom chords of the pivot span of the Pennsylvania

Fig. 1.



Beam Pile.

Fig. 2.

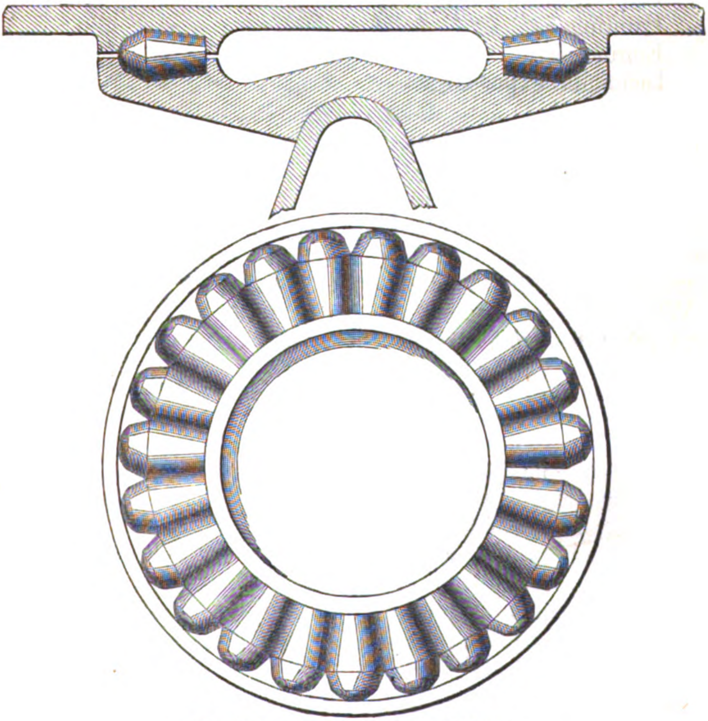


Finished Beam.

Railroad bridge, it should be mentioned that they are rolled in a peculiar manner, and that it has been proposed to employ beams of the same kind, but of greater depth, for bridging considerable spans. Figs. 1 and 2 show sections of the beam pile and of the finished beam. The parts of the beam pile intended to be rolled out into the top and bottom flanges are first rolled into slabs by themselves, with a deep groove on one side. That portion of the pile intended to form the web is then fitted between these slabs, and the pile, thus approximating to the form of the finished beam, is then easily rolled out between rolls of moderate diameter, with comparatively little power, and without crushing, or other injury to the edges of the flanges.

The pivot, upon which the turning span of the bridge just described is made to revolve, is of a kind now extensively employed in the States for railway turntables, Fig. 3. It consists of a fixed

Fig. 3.



Turntable, and Pivot for Turning Bridges.

and of a movable cast iron disc, both being circularly grooved out to receive a number of steel rollers, each turned to the frustra of a double cone. A circular railway, upwards of 30 feet in diameter, is laid around the pivot, for a turntable 48 feet diameter, and wheels are fitted beneath the bridge, to bear upon this railway only when the bridge does not balance truly on the conical rollers. With a weight of 14 tons balanced upon one of these bearings,—this weight consisting of an iron turntable 54 feet in diameter,—the whole was revolved by a weight of 3½ lbs. hung over a pulley, and connected by a cord to the periphery of the turntable. In the case of railway turntables fitted with these bearings, the heaviest engines are turned by pressing against them by hand, no gearing being now employed. Pivots of the same kind have been applied to two turning bridges of cast iron, each 230 feet long, and covering two openings of 100 feet each. One of these bridges is at Galena, the other at Chicago, both in the state of Illinois.

The form of truss introduced by Mr. Wendel Bollman, C.E., may next be noticed. This has been extensively adopted upon the Baltimore and Ohio Railroad, where it was first introduced eleven years ago. In this bridge the load upon each panel is transferred directly to the ends of the truss through a pair of straight suspension bars, doing duty only in that panel. With the exception of one pair of suspension bars, supporting the centre of the bridge, the bars in each pair are of unequal length, and their lower ends are attached to the upper extremity of a compensating link in order to allow for contraction and expansion. The bridge cannot alter its form under unequal loading. A bridge upon this plan at Harper's Ferry, on the line of the Baltimore and Ohio Railroad, has four parallel trusses, for a double line, and a clear span of 124 feet. (Plate 20, Fig. 5.) The span is divided into eight panels, and the depth of the truss is 17 feet 6 inches, or 0·137 of the span. The top chords are each formed of a single line of octagonal cast-iron pipes, 12 inches in diameter, and having 36 square inches of cross sectional area. The vertical posts are of cast iron, and one-eighth of the whole weight of the truss and its load is supported at the foot of each post. The weight at the foot of the middle post of the truss is transferred, one-half to each end of the top chord, through a line of suspension bars 67 feet long. Each line is formed of parallel bars, 2⅛ inches by 1 inch, connected together by eyes and pins, the sectional area in each line being 4¼ square inches. The load at the foot of each end post is transmitted, in the ratio of seven-eighths to the nearest and one-eighth to the farthest pier, by similar lines of bars, the longer of which is 112 feet 7 inches, and the shorter 25 feet 3 inches. The shorter line is formed of bars, in pairs, 1½ inch by ⅞ inch, and has 2⅝ square inches of sectional area. The longer line is formed of bars, in pairs, 1⅝ inch by 1 inch, and has

3¼ square inches of sectional area. The strains upon the various parts of the truss, caused by the weight of the bridge and of a load of 1½ ton per lineal foot, are 2·8 tons per square inch in compression in the top chord, and vary from 4·46 tons per square inch in tension in the longer suspension bars to 7·14 tons in the shorter bars. There are seven different lengths of suspending bars, and the maximum calculated strains in these vary from 10,000 lbs. per square inch of the longest bars, 11,000 lbs. in the next size, and so on, successively, through 12,000 lbs., 13,000 lbs., 14,000 lbs., and 15,000 lbs., up to 16,000 lbs. per square inch in the shortest bars. The weight of this bridge, including timber work, has been given by Mr. Bollman as 21½ tons of iron and 13½ tons of timber for each span for a single line; but the Author finds, by calculation, that the iron-work must weigh considerably more than this, and he is disposed to take it as 6 cwt. per foot of single line. Mr. Bollman states, that the bridge was tested with a moving weight of 122 tons of locomotives on one span of single line, or nearly 1 ton per foot run, and that the deflection at a speed of 8 miles per hour was 1⅜ inch at the centre, equal to $\frac{1}{1100}$th of the span. The Author believes that no bridges upon this plan have been erected of a greater span than 160 feet. One of five spans, of 160 feet each, crosses the Muskingum River, at Zanesville, on the line of the Central Ohio Railroad.

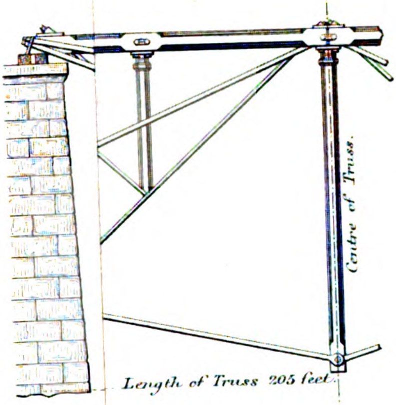
The iron bridge designed by Mr. Albert Fink, C.E., has been more extensively adopted than any other on the railways of the United States. (Plate 20, Figs. 6 and 7.) In this bridge a pair of diagonal tension bars connects the foot of the principal strut, or 'king post,' in each truss, with the ends of the top chord. This pair of diagonal bars supports one half of the whole weight of the truss and its load. Each half span is subdivided by a strut, and two diagonal tension bars extend, one to the nearest end of the top chord, and the other to the top of the centre post. Each quarter span is again subdivided into eighths, and these again, for spans greater than 100 feet, into sixteenths. In a truss of this kind, having sixteen panels, the weight at the bottom of the strut nearest to either of the piers is distributed as follows:—Calling the weight one, one half is transferred directly through a tension rod to the nearest end of the top chord, and thus upon the pier. The other half is carried up to the top of the second strut from the pier, and is received at the bottom of that strut by a pair of tension rods, which subdivide this half between them, one fourth being taken directly to the nearest pier, while the other fourth is transferred to the top of the strut at the quarter span. This fourth is again subdivided at the foot of this strut, one eighth being transmitted through a tension rod to the nearest pier, while the other eighth passes to the top of the middle strut of the whole span, and is received at the foot of this strut by the main tension rods, which thus transmit, each one sixteenth of the original load, to each pier. Thus the weight at the foot of the first strut from the end of the truss is distributed as follows:—One-half, one-fourth, one-eighth, and one-sixteenth, or, in all, fifteen-sixteenths of that weight reach the top of the nearest pier, through four converging sets of tension rods, while the remaining sixteenth reaches the opposite pier, after having been first brought to the foot of the centre strut, through the intervention of three separate systems of tension bars. With the exception of the load at the foot of the centre strut, which load is transmitted directly to the piers, the loads at the bottoms of the vertical struts are more or less subdivided, in the manner just described, before reaching the ends of the truss. It may be mentioned, that a few years after Mr. Fink had executed bridges upon this system, it was introduced to the notice of English Engineers by Mr. Pittar. Under the direction of Mr. B. H. Latrobe, C.E., then Engineer of the Baltimore and Ohio Railroad, Mr. Fink erected, in 1852, an iron bridge of three spans, of 205 feet each, on that line, where it crosses the Monongahela River (Plate 20, Fig. 7). The trusses for a single line are 16 feet apart from centre to centre, and the main tension chords are attached to the foot of the centre strut, 22 feet 8 inches below the centre of the top chord, thus giving a depth of truss equal to 0·11 of the span. The top chords and the centre struts are of cast-iron pipes, octagonal in their external form, 12 inches diameter between their parallel surfaces, and 10 inches in internal diameter, thus giving 41 square inches of section. The main tension rods in each truss are each formed of six bars, 4½ inches by 1¼ inch, giving a section of 33¾ square inches. The vertical struts, with the exception of the centre strut, are cast-iron octagonal pipes, 8 inches in external and 7 inches internal diameter. This bridge, and others by the same Engineer, are not proportioned to sustain heavy loads with so little strain as the Murphy-Whipple Bridge, already described; but, for a span of 205 feet, Mr. Fink's bridge, including the permanent way, weighs only ½ ton per foot of single line, and with an additional load of 1 ton per foot run, the tensile strain upon the wrought iron would not exceed 5·15 tons per square inch, and the compression on the cast iron 4·25 tons. The trusses rest, at the ends of the top chords, upon iron towers, swing links being employed instead of rollers, to allow for expansion and contraction. In the case of the bridge over the Monongahela River, the railway is carried at a little above the level of the bottom of the truss. The tension rods are attached at their lower ends to transverse timbers, upon which longitudinal timbers are laid to carry the rails. To prevent the timbers from swaying under the impulse of passing trains, cast iron longitudinal distance pieces are interposed between the feet of the vertical struts. The line of distance pieces thus formed has the appearance of a bottom chord, or tension member, but must not be mistaken for one. The same arrangement for supporting the roadway is also adopted in an iron bridge of two spans, of 205 feet each, over the Barren River, on the line of the Louisville and Nashville Railroad. But in the Green River Bridge, on the same line, the rails are carried above the level of the top chord, and only the vertical struts and the diagonal tension rods appear below. Instead of suspension links, rockers are placed under the ends of these trusses to allow for the effects of temperature. The Green River Bridge is the largest work of the kind yet executed by Mr. Fink, having three spans of 205 feet each, and two of 180 feet, the rails being 115 feet above low water. The construction, dimensions, and strength of the 205 feet spans of this and of the Barren River Bridge are identical, or very nearly so, with those of the Monongahela River Bridge, already described.

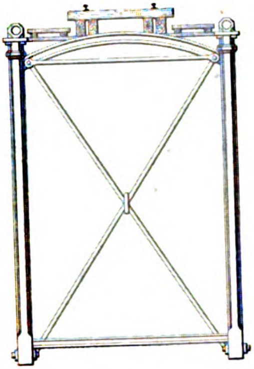
The Bollman and Fink trusses for a single line, and in spans of from 160 feet to 200 feet, cost £14 per lineal foot, or nearly £28 per ton, while timber bridges of the same span cost but from £5 to £7 per lineal foot. Even at this comparatively great cost, iron bridges are now meeting with an amount of favour in America, which appears certain to insure their ultimate substitution, for most of the timber bridges on the railways of that country. A gradual preference, too, is being shown for the plate girder; and already, on one or two of the New England railways, plate girders of nearly 100 feet span have been erected. These have drilled rivet holes, the edges of the plates are planed, and the working strain on the iron is only 4 tons per square inch. The trussed bridges which have been described have much more stability than might be supposed; but the great annual range of temperature, from 20° below zero to a reflected heat of 130° in the summer sun, or a total range of 150°, is not favourable to the use of cast iron in structures of such importance as railway bridges. The trusses described cost less at the outset than plate girders of the same strength, but if wrought iron were employed throughout in the trusses, they would then become more costly. The Canadian Engineers now import best Staffordshire plates, at a cost of £13 per ton, including freight and a duty of ten per cent. levied by the province, and these are made into girders at the Great Western Railway Company's workshops, at Hamilton, at a cost of £7 10*s*. per ton, making the whole expense of the girders £20 10*s*., which sum includes no profit. Girders of considerable weight have been made at this price at Hamilton.

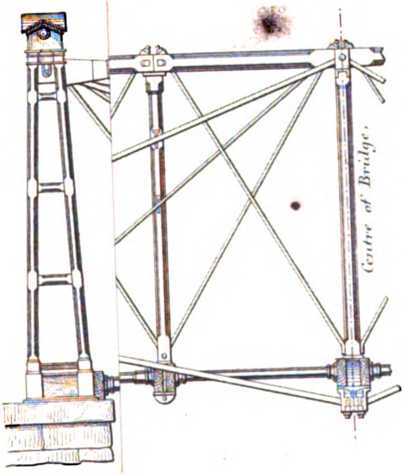
It should be mentioned that most of the iron bridges erected on the Great Western Railway of Canada have been made by Messrs. Fairbairn & Co., of Manchester.

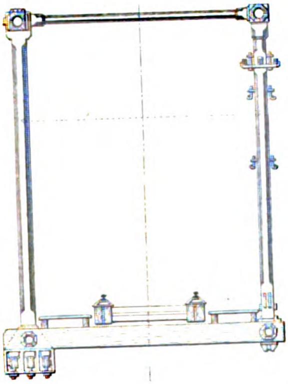
In conclusion, the Author would acknowledge the assistance he has received from Messrs. J. W. Murphy, Wendel Bollman, and Albert Fink, Civil Engineers practising in the United States, each of whom supplied the original drawings from which those now exhibited, in illustration of their respective bridges, have been copied. He is also indebted for important information to Captain Meigs, United States Engineers, and to Mr. Strickland Kneass, Engineer to the City of Philadelphia.

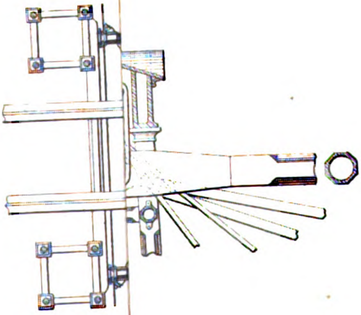
The Paper is accompanied by a series of diagrams, from which Plate 20 and Figs. 1, 2 and 3 have been compiled.

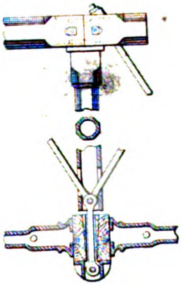

Centre of Truss.
Length of Truss 205 feet.




Centre of Bridge.







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KELL BROS LITHRS CASTLE ST HOLBORN.

Mr. ZERAH COLBURN said, he had refrained from entering more into detail, to avoid making the Paper tedious, but he should be happy to reply to any questions. No doubt, in looking at the diagrams, it would be considered that American engineers had practised great economy in designing these bridges. The fact was, that if bridges could not be constructed of iron at a moderate cost, the Railway Companies in the States would not adopt them, but would continue to use timber bridges, which could be built at from £5 to £7 per lineal foot. It was on the score of cost, alone, he believed that American engineers had adopted cast iron for all parts in compression; so many square inches of section could be put into the tubular form for one-third the cost in cast iron that would be incurred with wrought-iron plates. In the case of the Green River Bridge, the top chords and the vertical posts were of cast-iron pipes. Care was requisite in casting the pipes. Mr. Fink tested the iron for all the pipes, and holes were drilled in the side that lay uppermost in the sand, to ascertain that the cores had not floated, and thus that the metal was of uniform thickness. The fact of cast iron being used in the top chords was a sufficient explanation, why bridges were not made continuous over two, or more, spans in America. In nearly all these bridges almost the whole of the iron was made to do work in carrying the load. They no doubt differed from what English engineers were accustomed to, and he feared the diagrams would present an extraordinary appearance to English eyes; but they were faithful representations.

Mr. Colburn then called attention to the drawing of a bridge with truss rods to every upright post. The span was 125 feet, and the depth was 23 feet from the centre of the top chord to the centre of the bottom chord; yet all the iron posts, the truss rods, the diagonal tension rods, and the leaning end columns were not together equal to a quarter of an inch in thickness of iron, if spread out as a plate, over the whole side, and half of that thickness was cast iron; still no portion of the iron was subjected to a greater working strain than 4 tons to the square inch. Under ordinary circumstances a working strain of 3 tons to the square inch was the utmost that existed. He contrasted with that design some plate girder bridges, erected three years ago, on the Boston and Worcester Railway. They were 87 feet span and 7 feet 6 inches deep. The plates were 6 feet 3 inches wide and 7 feet 6 inches high. At every vertical joint there was a pair of butt straps, 8 inches wide, double riveted on each side of the web, and over these a pair of angle irons, 3 inches by 6 inches. Midway between the vertical joints, there were two angle irons, 6 inches by 3 inches, the longer sides being turned over at right angles, to form a knee by which they were riveted to the top and bottom chords. Mr. Philbrick, the engineer, adopted that form of stiffening the webs of girder bridges, because, as he said, he had found that in England and in France, the T irons used for stiffening had begun to split in some cases. He had only called attention to the butt straps and angle irons used by Mr. Philbrick, because these, spread out as plates over the side of the web, were alone equal to one-quarter of an inch in thickness, while in the Murphy-Whipple Bridge the whole of the members forming the web amounted to less than a quarter of an inch.

He might add, that none of the bridges shown in the drawings had broken down, and he had never heard that they had exhibited any signs of weakness. They were considered in America, and he believed them to be, very strong, and good bridges. If they had any peculiar merit, it might be in the fact that they were not overloaded with ballast. The trusses were deeper, and, therefore, there was not so much iron put into the sides as might be expected to keep the strains down.

In Bollman's Bridge the test load was 1½ ton per lineal foot, for a single line. In America the assumed load was arrived at, by supposing that there was on the bridge a train of loaded goods' waggons, with two engines and a snow plough weighing about 15 tons; and, in addition, when the bridge had a floor, that this was covered with snow, equal to a weight of 30 lbs. per square foot of floor; and that a side wind, equal to 30 lbs. per square foot was blowing. It was further assumed that, as every wheel had a break, all the breaks were put on at once, which would throw the strain upon the top chords of the bridge. That was the assumed load of the bridge of 200 feet span, and it was adopted by Mr. Murphy, Mr. Whipple, and Mr. Bollman.

In answer to inquiries from several members, Mr. Colburn said that the highest breaking strain of the cast iron alluded to in the Paper was 20½ tons per square inch; but it was certainly never subjected to that strain in a bridge. It was boiled cast iron, that was melted and kept in fusion for several hours, and partially decarbonized. Previous to the present war in America, every cast gun was made of iron melted two, three, or four times.

Mr. F. J. Bramwell regretted to hear that the arrangements for the reading of other communications were such, that it was desirable to limit the present discussion; as he feared there would be great difficulty in investigating the principles of construction of the Trusses described in the Paper, unless some considerable time were devoted to that purpose.

Before entering into the question of the Trusses, however, he wished to give a few facts bearing on the strength of cast iron. They were corroborative, to a great extent, of the statement on this subject made by the Author. That statement seemed to excite surprise, but Mr. Bramwell was quite prepared for such a statement, having had occasion, some time back, to investigate the strength of a particular quality of cast iron, which gave results nearly agreeing with those mentioned in the Paper. He exhibited two samples of Acadian cold blast iron, the produce of Nova Scotia, which had been broken, in his presence, by the proving machine at Woolwich Arsenal. Being No. 1 iron, a mixture of scrap was required before strength could be obtained. But as the experiments were made to test the quality of this individual iron, it would have rendered those experiments nugatory, had scrap from any other source been mixed with the iron. The only way of proceeding, that occurred to him, was to melt some of the iron into pigs, to make scrap for the second melting, reserving trial bars of the first melting. The order of the experiments was as follows:—The iron was put into an air furnace, and as soon as it was fused, eight sample bars were cast. These bore an average tensile strain of $7\frac{1}{2}$ tons per square inch of section. The iron was kept in fusion, and two hours after, eight other bars were cast. These did not break until a strain of 8 tons 6 cwt. was attained, being nearly 1 ton more per square inch than the strain which broke the first lot of bars. After a further interval of one hour and three-quarters, eight other bars were cast, which broke with a strain of $10\frac{8}{10}$ tons; so that by keeping the metal in fusion for three hours and three-quarters, the tensile strength was increased from 7 tons 10 cwt. to $10\frac{8}{10}$ tons, or about 50 per cent. The iron was then poured out, and pigs were cast from it. On the next occasion, the furnace was charged with half of the fresh No. 1 iron, and half of the pig iron from the prolonged fusion. The result was, that the bars cast immediately upon melting required for their fracture a tensile strain of 11 tons; while those cast after two hours' continued fusion only bore 9 tons 4 cwt. As this result did not agree with those obtained from the bars cast before and from those cast after this particular lot, Mr. Bramwell had no doubt, there was some error in the marking to identify these bars. The bars that were cast after two hours' further fusion gave an average tensile strength of $18\frac{1}{2}$ tons. The strongest, of which he exhibited a sample, did not break until the tensile strain per square inch rose as high as 19 tons 12 cwt. As an evidence of the unusual strength of this iron, he might state that the whole of the weights belonging to the proving machine were not quite sufficient to enable this strain to be applied, so that extra weights had to be obtained. This sample of cast iron was undoubtedly the strongest that had ever come under his notice. The specific gravity of the metal increased from 7·09 for the No. 1

pig, to 7·29 for the sample which bore the strain of 19 tons 12 cwt.

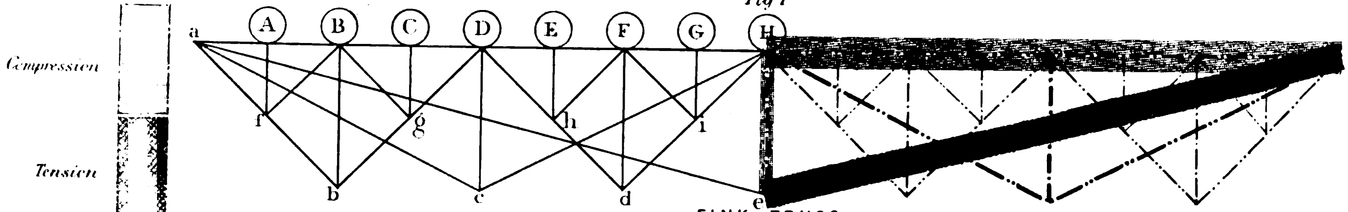
The Author, in alluding to the method of melting iron in America, stated that its toughness was increased. Mr. Bramwell hardly knew in what sense the term toughness was used. If it meant merely tenacity, or capability of bearing tensile strain, no doubt that was increased; but if it meant tensile strain, coupled with movement through a considerable space before rupture took place, so that the 'work done' to produce fracture would be large, then he questioned whether the melting spoken of did, after a certain point, add to such toughness; although no doubt it added to the power to bear a great load, if very gradually and quietly applied. He regretted that there were no means of ascertaining, by the machine at Woolwich, the facts involved in this question of toughness. The samples were however tested for their power to resist compression. This was found to be, practically, about three times and a half greater than that to support tensile strain; a lower ratio no doubt than was ordinarily obtained. It would perhaps be considered surprising, that the iron he had spoken of was rejected as being bad, because it contained silicon. It must be borne in mind, that this silicon could not be detected in the behaviour of the iron, but required the careful analysis of the chemist to discover it. Nevertheless, the silicon being there, the iron was as much condemned as if the silicon had exercised its supposed baneful influence, so as to render the iron bad under mechanical test. This seemed to him to be yielding too much to chemical authority, which, after all, must base its opinion, as to the injurious, or non-injurious, character of any foreign substance in a metal, upon the results derived from mechanical test.

With regard to the principles involved in the construction of the Trusses of American Iron Bridges, he referred to three diagrams (Plate 21) he had caused to be prepared, showing, respectively, the Fink truss (Fig. 1), an ordinary diagonal truss which was so well known in this country (Fig. 2), and the Bollman, or Harper's Ferry Bridge, truss (Fig. 3). In these diagrams, one-half of each figure was drawn merely in lines, running along the centres of the various members of the truss; while in the other half of each figure the members were indicated either by dotted lines simply, or by dotted lines and shading on each side, so as to show, by the width of the shading or of the dotted lines, the relative amounts of iron required in each member; and by the different kinds of dotted lines and the different kinds of shading, to distinguish between the parts in compression and those in tension; discarding, for the sake of simplicity, all consideration of rivet holes, joints, and such

AMERICAN IRON BRIDGES.

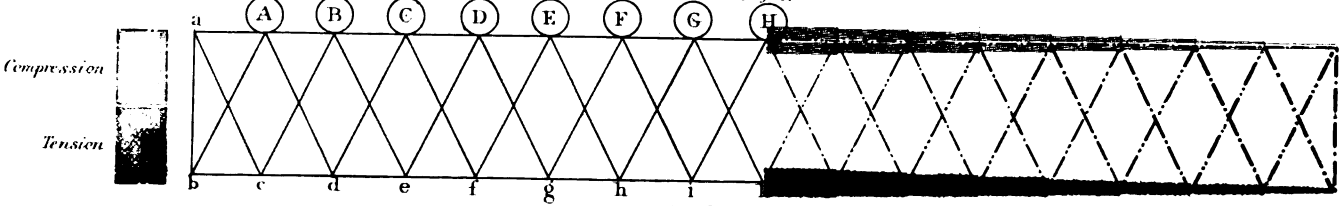
PLATE 21 VOL. XXII.

Fig 1


Compression
Tension
a
A
B
C
D
E
F
G
H
f
g
h
i
b
c
d
e

FINK TRUSS.

Fig 2.


Compression
Tension
a
A
B
C
D
E
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G
H
b
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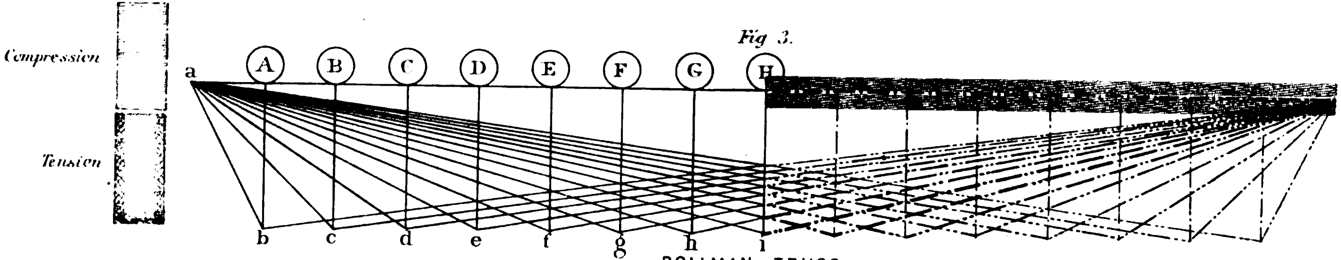
d
e
f
g
h
i

DIAGONAL TRUSS.

Fig 3.


Compression
Tension
a
A
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i

BOLLMAN TRUSS.

F. J. BRAMWELL, DELT.

Minutes of Proceedings, Institution of Civil Engineers Vol. XXII Session 1862-63

[illegible]

matters, and assuming the whole of the iron to be brought to an uniform thickness, and to be equally valuable for compression and for extension. Thus if the shading along one member of the truss were twice as wide as along another, then it indicated that there must be double the sectional area of metal in the first of these two members, that there was required to be in the second of such members. In this way the diagrams would at once instruct the eye, as to the consumption of metal in each part of each truss, while the difference of the shading would show, which part was in compression and which in tension. Further, at the end of each figure a parallelogram had been drawn, which indicated the relative amount of each kind of metal required in the three different trusses. Assuming that there would be no special circumstances of convenience, or inconvenience, attending the manufacture of any particular truss, there could be no question, that was the best truss which consumed the least metal in its construction. And if the decision, as to the merits of the Fink truss (Fig. 1), and of the Bollman truss (Fig. 3), were to be arrived at by the consideration of this test, Mr. Bramwell believed he was correct in saying, that they were both of them inferior to the ordinary diagonal truss (Fig. 2), and in the following ratio :—

Diagonal	truss	required	262	parts of metal.
Fink	,,	,,	396	,,
Bollman	,,	,,	370	,,

The distribution of the metal would be as follows :—

DIAGONAL TRUSS :	Compression . . .	136	
	Tension . . .	126	
			262
FINK TRUSS :	Compression	200	
	Tension	196	
			396
BOLLMAN TRUSS :	Compression . . .	185	
	Tension	185	
			370

These results were arrived at by a calculation which he believed to have been based on correct principles, and to have been accurately worked out. He would, however, endeavour to explain the causes of the extra consumption of iron in the Fink and the Bollman trusses.

First, as to the Fink truss:—The diagram was made on the assumption, that the depth of this truss, and of course of the other two trusses also, was one-eighth of the span, and that the truss was loaded with fifteen units of load, one over each of the vertical struts. The struts on the left-hand side were lettered from A to H, the latter letter being over the central strut. The effect of these units of load would be, that unit A would, by its vertical A *f*, be carried one-half by the tie rod *f a*, and one-half by *f* B; and that the unit B would be carried on its vertical B *b*, which would also have to carry the half of unit A, brought on by the tie-rod *f* B, and also one-half of the unit C, brought on, in a similar manner, by the tie-rod *g* B. In this way the vertical B *b* would get a load of two units, one-half of which, or one unit, would have to be upheld through the tie-rod *b a*, but as the upper part, *f a*, of this tie was already strained by the weight due to one-half of the unit A, and as the angle of the tie was 45°, the tie *b a* would bring a compression of exactly a unit and one half on the top member of the girder. It was clear that a downward load of one unit and a half must also be brought, by the tie *b g* D, on to the point D, and that a similar load of a unit and a half must be brought on to the same point by the tie *d h* D, making together a load of three units. This added to the unit D itself, would cause a load of four units to have to be carried by the vertical D *c*. Of these four units two would be carried by the tie *c a*, and the other two by the tie *c* H. The tie *c a* would bring the compression on to the top member of the girder due to these two units. If the tie *c a* had been at the same angle as the tie *b f a*, this compression would only have been two units; but as the tie *c a* was at an angle only half as favourable as the tie *b f a*, the compression brought on to the top member of the truss by the tie *c a* would be double that of the vertical load carried by it, or a compression of four. The last source from which compression would come upon the top member of the truss would be from the strain of the tie *e a*. This tie, it would be seen, had to bear one-half the duty of upholding the central strut H *e*. This strut H *e* would have to support, first, two units of load brought on it by the tie *c* H; secondly, one unit of load brought on by the tie *d i* H, owing to that tie upholding one-half of the load of two on F *d*, and, thirdly, one-half of a unit of load brought on by the upper part *i* H of the same tie *d i* H, which upper part would have to support the half of the unit of load on G *i*. These three sources of strain would amount together to three and a half units. There would of course be an equal load brought on by the corresponding ties to the right hand of the strut H *e*, which strut would thus be loaded with seven units, to which must be added the unit on H itself, making eight as the total load on the strut H *e*. Of this eight, one-half, or four, would be upheld by the tie *e a*, and by this tie would exert a compressive force on the top member of the girder. It would be seen, that the angle at which this tie *e a* lay was twice as unfavourable as that of the tie last considered, and four times as unfavourable as that of the tie *b f a*, the angle of which was 45°. Owing to this unfavourable angle of the tie *e a*, the load supported by it would exert a compression of four times its own amount, or sixteen. The sum of the compressions, therefore, on the top member of the girder would be,

For the	tie	*f a*	½	unit × by	the effect	of the	angle	1 = ½
,,	,,	*b a*	1	,,	,,	,,	,,	1 = 1
,,	,,	*c a*	2	,,	,,	,,	,,	2 = 4
,,	,,	*e a*	4	,,	,,	,,	,,	4 = 16
								21½

It would be seen, that this compression extended from end to end of the top member of the truss, so that the top member would require to have as great a sectional area at the extremities as in the middle. Assuming that one part of iron was required to resist one unit of load, then the sectional area would be 21½, and the length of the truss being taken as 8, the amount of iron consumed in the compression bar would be equal to 21½ × 8, or 172 parts of iron.

Before considering the amount of iron in the other members of the Fink truss, Mr. Bramwell would compare the compression bar, or top member, of this truss, with that of an ordinary diagonal truss (Fig. 2). In the latter case it was well understood, that as fifteen units of load, distributed as shown, were equal to a central load of eight, and as the girder was eight times as long as it was deep, the compression in the centre would of course be sixteen units of load. This then would represent the maximum sectional area, which would exist only at the very middle of the compression member, as it would become less and less towards the ends of the girder; the diminution being in such a ratio, if the number of points of attachment of the ties and struts were infinite, as would give a parabolic curve, the area of which would of course be two-thirds of the parallelogram containing it. Therefore $16 \times \frac{2}{3} = 10\frac{2}{3}$ would represent the average depth of the compression member, which multiplied by the length 8, would give $85\frac{1}{3}$ as the amount of iron in that member, or rather less than one-half of the iron in the similar member of the Fink truss. In the diagonal truss, with the number of ties and struts as drawn, this theoretic amount was diminished only to the extent of $1\frac{1}{3}$; that was to say, the whole amount of iron was 84, arrived at thus :—

					Pressure.
Between the points	*a* A	the compression would be	3½ units,	which, multiplied by the effect of the angle =	1¾
”	A B	”	10½	”	5¼
”	B C	”	16½	”	8¼
”	C D	”	21½	”	10¾
”	D E	”	25½	”	12¾
”	E F	”	28½	”	14¼
”	F G	”	30½	”	15¼
”	G H	”	31½	”	15¾
Giving for the sum of the compressions					84

This divided by the number of spaces 8, made 10½ as the average depth.

It was, he thought, not improbable that a cursory view of the drawing of the Fink truss might lead to the idea, that it was one that must be economical; inasmuch as it appeared to have a compression member only, and to be without any corresponding formal tension member, the diagonal ties being made to serve the purpose of a regular tension member. But even if this were so, and if the ties were made at no greater consumption of metal than the ties and struts of a diagonal girder, which he would prove was not the case, even then the Fink truss would have no advantage; inasmuch as its one compression member contained slightly more iron than the compression member and tension member together of the diagonal truss. He had stated that the compression member of this latter girder contained 84 parts. The tension member contained rather more, thus,—

					Tension.
Between the points	*b c*	the tension would be	4 units,	which, multiplied by the effect of the angle =	2
”	*c d*	”	11	”	5½
”	*d e*	”	17	”	8½
”	*e f*	”	22	”	11
”	*f g*	”	26	”	13
”	*g h*	”	29	”	14½
”	*h i*	”	31	”	15½
”	*i k*	”	32	”	16
Giving for the sum of the tensions					86

This, divided by their number 8, made 10¾ as the average depth. The amount of metal 86 in that member, added to that in the compression member, gave 170 parts for the metal in those two members, as compared with 172 parts in the compression member alone of the Fink truss.

He would now revert to the consideration of the Fink truss:—

It would be remembered that the main tie bar *e a* had to transmit four units of load; but these became multiplied in their power of strain on the tie, by the number of times the length of that tie exceeded the depth of the girder. This depth being 1, and the half length of the girder being 4, the length of the tie would of course be equal to $\sqrt{1^2+4^2}=\sqrt{17}$. The strain, therefore, would be the load $\times\sqrt{17}$. But as the length of the tie was also $\sqrt{17}$, it followed that the amount of metal must be $\sqrt{17}\times\sqrt{17}\times$ the load of 4; in other words, the amount of metal increased as the square of the length of any sloping tie. In this

	Parts of Metal.
case the amount was 2 ties each 17×4 =	136
Similarly, it could be shown, that the ties *ca*, cH, and their counterparts on the other side of the truss, would require $\sqrt{5}\times\sqrt{5}\times2$ load $\times$ 4 of them =	40
That *b a*, *b* D, *d* D, *d* H, and their counterparts on the other side of the truss, would require $\sqrt{2}\times\sqrt{2}\times1$ load $\times$ 8 of them . . . . =	16
and that the upper parts of these ties, *f a*, *g* D, *h* D, *i* H, and their counterparts on the other side of the truss, with the corresponding short ties, *f* B, *g* B, *h* F, *i* F, and their counterparts on the other side of the truss, would require $\sqrt{\frac{1}{2}}\times\sqrt{\frac{1}{2}}\times\frac{1}{2}$ load $\times$ 16 of them . . . . =	4
Making the total of iron in tension, as already stated,	196

	Parts of Metal.
Further, the compression member, it had been proved, would contain	172
The strut H *e* would contain 1×8 units . . . . =	8
The strut D *c*, and the corresponding one on the other side of the truss, would contain 1×4 units $\times$ 2 of them =	8
The struts B *b*, F D, and their corresponding ones on the other side of the truss, would contain 1×2 units $\times$ 4 of them . . . . =	8
The struts A *f*, C *g*, E *h*, G *i*, and their corresponding ones on the other side of the truss, would contain $\frac{1}{2}$ long $\times$ 1 unit $\times$ 8 of them . . . . =	4
Making the total of iron in compression, as already stated,	200

In order to complete the comparison between the Fink truss and the diagonal truss, it would be necessary to ascertain the amount of metal in the struts and ties of this latter truss. The lengths of the various struts and ties would be uniformly $\sqrt{1\frac{1}{4}}$, the multiple of strain would therefore be $\sqrt{1\frac{1}{4}}$, and the amount of iron in each of them $1\frac{1}{4}\times$ the units of load:—

On the strut	A *b*	there would be	4	units.
"	B *c*	"	3½	"
"	C *d*	"	3	"
"	D *e*	"	2½	"
"	E *f*	"	2	"
"	F *g*	"	1½	"
"	G *h*	"	1	"
"	H *i*	"	½	"
Making a total of			18	"

This sum, multiplied by the 1¼, would give . . .	22½
To which must be added the end upright *a b* . . =	3½
Making	26
Or, for the two sides of the truss	52
Adding the amount of metal in the compression member before given	84
The total of iron in compression would then be, as already stated	136

Next, as regarded the parts in tension :—

On the tie	*a c*	there would be	3½	units
"	A *d*	"	3	"
"	B *e*	"	2½	"
"	C *f*	"	2	"
"	D *g*	"	1½	"
"	E *h*	"	1	"
"	F *i*	"	½	"
"	G *k*	"	0	"
Making a total of			14	"

This, multiplied by 1¼, would give	17½
Making for the two sides of the truss	35
Adding the amount of metal in the tension member before given	86
The total of metal in tension was thus found to be . .	121
But to this should be added the ties G *k*, which, although not called into action, when an uniform load was on the girder, would have to bear a strain if the load were a passing one. They might then be required to support a single unit of load. Under similar circumstances two ties on each side might require to be strengthened, so as to bear a further half unit each; then 4 ties 1 unit × the 1¼ . . . . =	5
Giving as the total of iron in tension, as already stated,	126

He would not occupy any further time, by entering into the details of the calculation of the quantity of metal in the Bollman Truss; but would simply refer to the figures already given, by which it would be seen, that while it was more economical than the Fink Truss, in the proportion of 37 to 39·6, it was less economical than the ordinary diagonal truss, in the proportion of 37 to 26·2.

The cause of the waste of metal in the Fink and in the Bollman trusses appeared to him, on a little consideration, to be sufficiently obvious. The strains which related to the centre part only of a truss, and which might be got rid of in a comparatively short distance near that centre, were, in the Fink and in the Bollman trusses, carried to the very ends of the compression member, so that the whole length of that member sustained a pressure that need only be borne near the centre. Further to carry out this bad arrangement, the tie-rods were of necessity placed at most unfavourable angles, by which not only was an unnecessary amount of metal consumed, but the already useless strain on the compression member was aggravated.

It was unnecessary to investigate the construction of the Murphy-Whipple truss, as the drawing showed that truss to be free from the radical error, of carrying the whole of the compression to the very ends of the top member. It was, however, clear, that the use of struts in a vertical position was not so economic, as the use of struts in a diagonal position, inasmuch as the struts when placed vertically did not assist in the progression (if such a term might be allowed) from end to end of the truss. The ties, also, were not disposed at the most economic angle; but with those exceptions, he had little doubt the Murphy-Whipple truss would, on investigation, prove to be one of good construction, and equal to such as were in ordinary use in England.

He regretted having to pronounce so unfavourable an opinion on these trusses; but he was glad to be enabled to do so, without the fear of his criticism being displeasing to the Author, who, it was understood, had merely submitted these particular trusses, as matters of interest in the history of railway works in America, without expressing approval of their construction, and for the very purpose of having their merits, or demerits fully discussed.

Mr. Fleeming Jenkin said, there was an apparent discrepancy in the general practice of Engineers in the use of cast iron under compression. From the Paper it would appear, that the cast-iron compression bars of all the girder bridges were strained up to a maximum of from 4¼ to 4½ tons to the square inch, whereas in the two cast-iron arches mentioned by the Author, the strain per square inch was limited to 2 tons and 1·6 ton respectively. Nevertheless, in both cases the strains were due to loads of a similar nature; and at first sight there was no reason why the cast iron should not be capable of bearing an equal strain in both classes of bridge. The practice in England agreed with that in America. The strain allowed on cast-iron arches was from 1½ ton to 2 tons as a maximum; whereas in columns and other constructions, strains of 4 tons were admitted without hesitation. He thought it was a point of some interest to examine, how it happened that under similar conditions the same material should be so differently treated. He believed the fact to be, that the calculated strains upon cast-iron arches were exceedingly fallacious; no experiments had been made upon the strains in metal arches, whether of cast iron or of wrought iron, whereas excellent experiments had been made upon girders and columns. The strains upon every part of a girder bridge were well known, and the metal could be accurately apportioned to the work it had to perform; whereas he was not aware of any experiment having been made on arches. The calculations which had been based upon the theory devised for stone bridges were, in his opinion, altogether fallacious, and he thought the subject deserved much more attention than it had hitherto received. The common formula, by which a cast-iron arch was calculated, supposed the existence of an uniform load. This formula gave the compression on the crown of the arch, as equal to the compression which would result at the centre of the top bar of a girder, of a depth equal to the rise of the arch, and loaded in the same manner. This calculation would be correct, provided the arch were formed of two rigid beams, such as the rafters of a house, hinged at the centre, and loaded uniformly, with reference to a horizontal line; but an arch was not hinged, nor perfectly flexible at the centre, nor were the two sides perfectly rigid; therefore the formula could only apply approximately. Still as the arch was really comparatively flexible at the crown and rigid at the spandrils, he believed the formula would, on experiment, be found sufficiently exact. On the other hand, he had never met with any satisfactory calculations of the strain thrown upon a metal arch bridge by a passing load. Professor Rankine mentioned, that a stiffening girder, similar to that required in a suspension bridge, would be required for a cast-iron arch; but, so far as he knew, no person had given the actual strains produced by a passing load, and it was in fact difficult to calculate them. The rigidity of the cast-iron arch played the part which the load over the spandrils took in a common stone arch, bringing the line of pressure from the crown down to the springings. That rigidity, or resistance to bending, was a difficult thing to calculate, especially with such forms as were now common, in which the rigidity was partly due to the main rib, partly to a top girder, partly to the intermediate filling of the spandrils, and partly to a sort of compound beam built of these three parts, which were usually very imperfectly connected. The large unknown strain, produced by the flexure due to a passing load, was, he believed, the practical reason why Engineers increased the section of the cast-iron ribs of arches, to such an extent as to reduce the maximum strain, when calculated from the uniform load alone, as low as 1½ ton or 2 tons; whereas they were able to allow 4 tons on the girder or column, because it was known from experiment, that the actual maximum strain upon these forms would not exceed the calculated strain. With the present form of arch it was almost impossible to calculate the strains. He had endeavoured to design a form of arch which, being a simple piece of framework, or trussing, would permit the calculation of the strains on every member, due to every arrangement of the load. Each member was strained in the direction of its length only. That form was shown in the model of an arch he had placed upon the table. He would not now enter upon a mathematical investigation of the subject, as he hoped soon to have an opportunity of practically testing the merits of that form, and he would then bring the results before the Institution. He thought he should be able to show, that a cast-iron arch could be made, in which the material was subjected to the full strain of 4 tons per square inch, and that such bridges could be built at less cost than the common plate, or parallel girder bridge.

Mr. E. A. Cowper could not allow the observations, with reference to the strains upon cast-iron arches to pass unchallenged. The Washington aqueduct might, perhaps, be taken as a good example of a column placed in the form of an arch. He argued that columns were often compressed with a greater pressure per square inch than arched ribs, if the whole section was taken as the area. A vertical column, without side strain or pressure, was in a very favourable condition for bearing weight; and indeed it was astonishing what columns would sustain. It had been stated, that if the column were in the form of an arch, there was great difficulty in calculating the compression per square inch. To this he dissented, believing that the strains upon a cast-iron arch could be readily estimated. It was necessary to ascertain, first, where the line of strain would come, under the various circumstances, of a passing load, &c., and having found how near the edge, or flange of the rib the strain would pass in the worst case, it was easy to calculate the section that it was necessary to give to the rib, so that the iron might be put to a fair strain per square inch. It was an expeditious, and if carefully performed, an accurate method, of finding the true line of strain of the Distorted Catenary Curve, to hang up a flexible chain to represent the weight and form of the rib, and then to load it, first with the various weights of the bridge itself, if the spandrils had any heavy filling-in, and then with the passing load in various positions. The true curves, under the various circumstances, would thus at once be obtained, and could be traced on a drawing-board, placed behind the chain. This plan he had practised for many years, no doubt in common with others, and had used it in settling the sections of the ribs of the Barnes, Richmond, and other bridges. Of course, in a bridge in which the strength was intended to be given entirely by compression, it was no more admissible to make the rib so shallow, as to allow the line of strain of any one of the distorted catenaries to pass outside, than it would be, to make a column for bearing compression so crooked, that the vertical line of pressure came outside the column. He need hardly say, that the true line of compression in a bridge would never follow the fancy curves that were often given to arches, such as semicircles and ellipses, but would always be in a catenary curve, more or less distorted, according to the various loads upon it and their position. He had, many years since, designed a suspension bridge, on precisely the same principle as that of an arch inverted, including all the lines of strain, or tension, within the chain, and providing sufficient depth in the section of the chain to take the tension where it came. The chain was, in fact, a wrought-iron plate, with top and bottom flanges, like an ordinary deep wrought-iron girder. Such a bridge would be perfectly stable, as it could not move out of shape, nor deflect from the elasticity of the material so much as an ordinary girder. When, however, it was intended that an arched rib should not depend entirely on compression, but should also rely on the tension of its material, from being made of wrought iron well bolted, or riveted together, or of cast iron, in pieces provided with substantial flanges, and proportionate bolts and nuts, then it might be looked upon, to some extent, as having the stiffness of a girder, and might be made so narrow, that some parts of the distorted catenaries would pass outside it, in which case it was easy to calculate how much compression there would be on one side and how much tension on the other side, as it was a simple case of leverage between the line of strain and the inside and outside flanges of the rib. He had stated that, under certain circumstances, an arched rib might to some extent be looked upon as a girder, and he had spoken thus guardedly, because an arched rib, thoroughly stiffened by bracing, or spandrils extending over the crown of the arch, and having a considerable depth, would so resist the action of rising and falling with the expansion and contraction due to variations of temperature, as to cause fracture in some part or other. For an arched rib presupposed fixed abutments to take the thrust, so that when the metal expanded by heat, the arch must rise, or break by crushing. This was not a fanciful objection, as it occurred in every-day practice. For instance, Southwark Bridge was erected in cool weather, so that in the full heat of the sun, the centre arch rose in the middle 1¾ inch, and the various castings forming the spandrils, being deep and well fitted together, without any allowance for expansion, began to break consecutively. The cause of fracture was owing to the stone abutments being fitted tightly against the ends of the spandrils. It had been found necessary to jump holes in the stone, immediately behind the ends of the spandrils, so as to relieve them, and to allow the rib to rise as it expanded. The effects of expansion and contraction in Southwark Bridge were well shown by the hand-railing drawing out of the stone piers in winter, and being thrust into them in summer, the play over the abutments amounting to ¾ of an inch. The stone paving was also always out of order over the piers, and in some cases the heavy stones had flushed at their top edges. He thought many more experiments ought to be made, on the end pressure that columns of various sections would bear. The few experiments of that kind which he had tried agreed very well with those made by Mr. Eaton Hodgkinson; but proper experiments with columns on a large scale were expensive, chiefly on account of the heavy pressures required to crush them. There was also danger in measuring the deflections when the crushing weight was nearly approached, as a hollow column, for instance, would be separated into many pieces, with great violence, when it was crushed or broken. He had found the want of reliable experiments of this class, when designing large shear legs of 120 feet in height, to lift 40 tons, and had been obliged to rely on his judgment alone as to strength: the result, however, had been satisfactory.

Mr. PHIPPS said, the Paper was for the most part limited to several varieties of trussed girders. On these he would not at present offer any observations, but would confine his remarks to one, or two iron arched constructions, also referred to in the Paper, as he had paid particular attention to the subject of cast-iron arches. Mr. Jenkin had truly remarked, that whenever these arched constructions were loaded irregularly, it became difficult to calculate the strain to which the material then became subject. For instance, iron arches, particularly on railways, might be loaded upon one-half of the span only. In such a case the curve of equilibrium would often shift so much from the middle of the arched rib, as almost to touch the extrados and the intrados of the arch on opposite sides of the centre. Having obtained, however, the position of the curve of equilibrium, it then became a question, how to estimate the effect of the pressure in its detrimental action on the outer fibres of the rib. This was a point upon which, he agreed, that no practical, or reliable, information was to be obtained from books, and, in consequence, he had invented a method which he had found both simple and accurate in its application. To illustrate the degree to which the shifting of the line of pressure might affect the strain upon an iron arch, when placed under compression, he stated that in a prismatic bar of iron, in shape like a 3-inch plank, the pressure on the outer fibres on one side would be doubled, and on the other side be reduced to nothing, by the removal of the line of pressure only the one-sixth part of the whole width away from the centre of gravity. Now in this, as in every other case, whenever a piece of metal, or other elastic material, was compressed by a force on any other line than that of its centre of gravity, the action upon the outer fibres might be obtained, by conceiving the material, first of all to be compressed squarely throughout, as if the strain were applied over the line of centre of gravity, and then, finding the strain due to the angular motion, by the same process that would be used for obtaining the strain on that portion of a cantilever contiguous to where it was attached to a wall; using the total compressive force applied as the weight, and the distance of that pressure from the line of centre of gravity as the leverage. Then the strain on the outer fibre thus obtained, added to the former square-on pressure, would give the whole detrimental action upon the outer fibre of the material. Thus, as he had previously explained in reference to the Charing Cross Bridge,[1] when a pressure of 475 tons was applied, square on, to a piece of iron of 161·25 square inches sectional area, all the fibres would be strained uniformly up to 2·94 tons on the square inch; but by removing the line of pressure 3·6 inches away from the centre of gravity, the pressure on the outer fibres would be increased up to 6·86 tons on the square inch. Mr. Phipps added that, in cases where the arched rib proper was well connected with the roadway bearer above, by an efficient system of diagonal bracing, the centre of gravity of the whole section of the arched rib and roadway bearer together must be taken, as that around which the previously-named angular motion must be computed.

Mr. F. W. SHEILDS could not agree, that the object of the bracing in a girder bridge was merely to keep the top and bottom members asunder, and to enable them to do their work. In his opinion the chief object of bracing in all parallel girders, was to carry the vertical weight of the bridge, with the extraneous load upon it, to the points of support at the piers; and that duty was just as important as, and quite distinct from, the work to be performed by the top and bottom flanges. The bracing ought to be specially designed for that duty, and in that view he thought the American bridges brought under their notice, even those of the simplest form, showed a want of scientific knowledge in their construction. Thus, if a girder bridge be supposed to consist of twelve bays, and the driving-wheels of a locomotive loaded with 12 tons rested over the third bay, that load would be transmitted to each pier, by the bracing, in the inverse proportion of the distance of the loaded point from the piers, being nine tons to the nearer, and three tons to the further pier. One of the diagrams exhibited was just in such a case, and he observed that at the third bay, there was no diagonal tie from the lower flange which could carry the load to the further pier. Consequently the girder would have to depend merely upon the rigidity of the top flange, considered as an independent beam of perhaps a few inches deep, for the transmission of that part of the load which reached the further pier, and which should be sustained by the whole girder of several feet deep. Diagonals of great inclination were not advisable, independent of all increase of strain arising from their inclination, as they were free to deflect on a curve struck from one of their ends as a centre and the other end as a radius, and that curve would coincide in practice, for a considerable distance, with a vertical line, so that there was little or no resistance to deflection. There were some bridges in the Regent's Park upon that principle, which fully bore out his foregone conclusions, for he found that by jumping upon those bridges, the whole could be set in motion by his own weight alone.

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[1] *Vide ante*, p. 535.

Mr. ZERAH COLBURN remarked, with reference to the comparison which had been made between the various trusses, that it was well understood in the States, as applying to the Fink and Bollman Bridges. The Murphy-Whipple Bridge (Plate 20, Figs. 3 and 4) was believed to be the best class known in the States; and if there was not much difference between that and many bridges in this country, it was no doubt owing to the fact, that when the principles were fixed, there could not be much room for difference between one good bridge and another.

Mr. HAWKSHAW, President, expressed his regret that, owing to the late period of the Session, and the necessity for reading two other Papers before its close, the discussion upon a subject of so much general interest as American Iron Bridges should have been necessarily restricted. The Institution was under great obligations to Mr. Colburn for the able and elaborate manner in which the communication had been made; and he hoped that the Author would, on other occasions, contribute to, and take part in, the proceedings.

May 12, 1863.

JOHN HAWKSHAW, President,
in the Chair.

No. 1,094.—"On the Communication between London and Dublin." By WILLIAM WATSON, M.A., T.C.D., Assoc. Inst. C.E.

HOLYHEAD, the nearest point of land in Great Britain to the metropolis of Ireland, was naturally thought of at an early date as a convenient port of departure and arrival for the mails; but though its proximity was undoubtedly the principal reason for its selection, yet it possessed also the advantage of being exactly opposite to Dublin, without any great difficulties in the navigation of the channel, and with easy access into the bay, at a time when shore lighthouses were scarcely known on that part of the coast.

This line of mail communication has been used for a century and a half. It is recognised in the Act of Parliament, passed in 1729, to confirm the patent previously granted to the Trench family, for erecting a lighthouse on the Skerries Rock,[1] near Holyhead, which authorised the payment of £50 a year by the Postmaster-General, in consideration of the benefit of the lighthouse to the packets sailing between Holyhead and Dublin. The communication between London and Dublin was then very irregular, and the time occupied on the journey was very protracted. Travelling through North Wales was attended with difficulty and fatigue, and the passage of the channel was altogether contingent on the state of the weather. Swift, in a letter to Pope, mentions the "quick change" which he "made in seven days from London to the deanery, through many nations and languages unknown to the civilized world." The poet Gay at another time speaks of "the plague which his friend suffered in the little smoky room at Holyhead," where he appears to have been kept weather-bound for ten days, and after "at last setting out he had been driven back by the storm, put to sea again, and was finally landed at Carlingford," sixty miles away from his destination. Fifty years afterwards, Edgeworth, passing through Dublin to cross the Channel, to visit his wife who was ill in England, says in his journal "just as I was going to embark in the packet, the wind became directly adverse, and I sat hour after hour with my eyes fixed on the weather-cock. Day after day the wind continued in the same point; no vessel could sail, and for more than a week I was thus kept in suspense." But even after fairly getting under weigh, the passage of the Channel, little more than 60 miles across, was often extremely tedious. In the journal and correspondence of Lord Auckland, recently published, Woodfall says, in a letter from Dublin to Mr. Eden, "Lord Mornington and his brother came over with me in the packet, and we had a great deal of political chit-chat one of the days (for we were near three on board)."

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[1] The history of this lighthouse is remarkable. It is stated in the preamble of the Act 3 Geo. II., "that the lighthouse which had been established by Mr. Trench under authority of the Charter from Queen Anne, he was no longer able to support from the duties then collected, and, that it must inevitably fall into decay unless the said duties were extended, and some further powers and encouragements given." Accordingly, increased powers and encouragements were afforded by the Act of Parliament to so great an extent as eventually to produce to Mr. Trench's representatives a clear revenue of £16,000 a-year. The Trinity House having been authorised by Act of Parliament in 1845 to purchase up the light, paid for it no less a sum than £445,000. The means were entirely provided out of the dues collected from commercial shipping.

This, however, was not the only case of an "improvident" grant made by the Crown or Parliament, adding to the burdens of shipowners; there were other private lighthouses, the interests in which were likewise purchased by the Trinity House, at a further cost of upwards of eleven hundred thousand pounds; all of which money was supplied from the dues which had been levied on shipping.

The public appear to have submitted with wonderful patience to the fatigues, delays, and inconveniences attending the journey between London and Dublin; and although, long before the close of the last century, measures of improvement were proposed, one of which was the construction of a bridge over the Menai Straits, no effectual means were adopted, until after the legislative union had taken place between Great Britain and Ireland, in the year 1801. Thenceforward, the necessary attendance of peers and of the representatives of the Irish constituencies in the Imperial Parliament could not fail to lead to the adoption of such improvements in travelling, and in the communication between the two capitals, as the advance of engineering skill of that day showed to be practicable. Public Commissions were constantly engaged in inquiries, and Committees of the House of Commons presented no less than twenty-four reports on the subject within ten years.[1] In these are described the various impediments which then existed in the way of public communication between the two countries and plans and proposals for improvements, principally in reference to the land part of the journey. Hills were to be reduced, more direct and perfect lines of road to be made, and the inconvenient, and at times dangerous, ferries near Conway and Bangor, in North Wales, to be bridged over, with the object of providing a continuous and easy road for the entire distance of 267 miles between London and Holyhead. A measure of such great national importance could not fail ultimately to obtain the cordial approval of Parliament. The late Sir Henry Parnell, one of the members for the Queen's County, took the most prominent part in urging forward the adoption of those improvements, and his persevering energy was ultimately rewarded with complete success. Large grants of public money were voted, and all other necessary means provided, to complete the arrangements for making this the most perfect road in the kingdom; even the short length of road between Howth and Dublin, on the Irish side of the Channel, was not overlooked. Nearly a million of money appears to have been expended on these works. The genius of Telford, aided by the talent of Macadam, having mastered every difficulty, in 1826 the astonished and admiring traveller was enabled to pass with regularity, safety, and comparative comfort over the entire distance from London to Holyhead in thirty-four hours.

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[1] The first of these Reports, made in 1810, is exclusively on the improvement of Holyhead Harbour, and recommends the expenditure of £67,862 on the construction of a pier for the use of the small sailing packets then employed in the mail service.

Improvements for the sea part of the journey had also engaged some degree of attention; but, while sailing vessels were in use, it was not thought that much could be gained in the passage of the Channel. In 1814, passages appear to have extended to three days in duration, and it is recorded, in the Parliamentary returns of that year, that for the space of nine days but one packet could sail, owing to adverse wind. In 1819, the average time occupied on the passage from Holyhead was about twenty hours, and about fifteen hours from Dublin. The vessels then employed were small cutters. Two years afterwards Sir Robert Seppings submitted designs for a superior class of vessel, 65 feet in length, 19½ feet beam, and of 102 tons burthen. The inferiority of the vessels previously employed in the service may thence be imagined.

The packet harbour at Howth was constructed, at a cost of £300,000, with the special object of facilitating the intercourse with England. Improvements, at considerable cost, were also provided from time to time, for the Mail Packet service at Holyhead, at the public expense. Indeed, nothing appears to have been overlooked, which could render more perfect the connexion of the several parts of the chain of communication.

The application of steam power for propelling vessels at sea, which was commenced in these islands by Henry Bell, in 1811, extended but slowly for some years; and no attempt was made to introduce the improvement for Channel navigation until 1819, when the 'Talbot,' of 156 tons, built by Wood, of Port Glasgow, with two engines of 30 H. P. each, by Napier, was placed on the

Holyhead station for the summer and autumn; and in the following year the 'Ivanhoe,' built by Scott, of about the same size, with engines, also by Napier, of 70 H. P. Their unexpected success overcame the professional prejudices of the experienced commanders of the sailing mail packets, who had recently recorded their opinion "that no vessel could perform the winter service with safety, but sailing cutters." Soon afterwards the 'Royal Sovereign' and the 'Meteor' were built specially for the Post Office service. The sailing cutters then disappeared for ever. The 'Royal Sovereign' was of 205 tons burthen, with two engines of 60 H. P. each. The 'Meteor' was 15 tons less in size, and had 20 H. P. less than her consort. The vessels were built by Evans, and the engines were made by Messrs. Boulton and Watt, who had also the honour of making the first engine placed in any vessel—namely that for Fulton, in 1804, and used by him in his first boat on the Hudson River. The performance of the 'Royal Sovereign' and the 'Meteor' fully established the advantage of steam. The average length of their passages in the first year between Holyhead and Howth was seven hours and thirty-three minutes, the shortest passage was five hours and forty-eight minutes, and the longest is stated to have been upwards of twenty-three hours.

The mail communication between London and Dublin had been thus long maintained exclusively by way of Holyhead; but the rapidly growing importance of Liverpool,—the sea-port of the manufacturing districts of Lancashire, Yorkshire, and Staffordshire,—justly claimed a direct postal service with Ireland, which was accordingly established in 1826, though the sea passage is more than double that from Holyhead. Packets of a larger size were built, and provided with more powerful engines. The Parliamentary returns, for a period of three years, give the shortest passage as having been made in eleven hours five minutes, while the longest exceeded thirty-five hours. Private enterprise, as early as 1819, had placed steam vessels on this station, for the conveyance of passengers during the summer months. In 1823, however, Mr. Charles Wye Williams, of Dublin, a venerable Associate of the Institution of Civil Engineers, originated a company for the maintenance of a regular steam communication throughout the entire year. His plan embraced not only the conveyance of passengers but of merchandize, an extension of the advantages of the regularity of steam transport till then unattempted. His plan was so eminently and immediately successful, that it was speedily adopted on other lines of the coast, and ultimately over the entire globe.

Though not, apparently, necessarily connected with the subject of the communication between England and Ireland, it is right to draw attention to the substitution of iron for timber in the construction of steam vessels, as having afforded great facilities for building models of the finest form, combined with lightness and strength, and the name of the first builder of an iron steam vessel should not be forgotten. Mr. Aaron Manby, the father of the Honorary Secretary of the Institution, built the first sea-going vessel of that material so early as the year 1820; in which year the first sea voyage was performed, when a cargo was conveyed direct from London to Paris without transhipment, the late Admiral Sir Charles Napier acting as captain, and Mr. Charles Manby as engineer. Many good authorities then questioned the innovation: now, scarcely any but iron steam vessels of every class, are used for commercial purposes. This material has also of late been extensively adopted for vessels of war. In fact it may be doubted, whether vessels of the form of those which now perform the Holyhead Mail Service could have been built of adequate strength of timber.

But if private enterprise was successful by sea, it was soon to be almost eclipsed by still greater success on land. The same spirit in England originated, and soon saw accomplished, that wondrous improvement of modern times, the railway. The line from London to Liverpool was completed in 1838; thenceforward that line became, for some years, the most expeditious route to Dublin, and the mails and passengers nearly deserted the Holyhead route. Liverpool did not, however, long retain this superiority. The proposal to continue the line of railway from Chester to Holyhead met with general acceptance; English enterprise again triumphed over every difficulty. The genius of Stephenson rivalled that of Telford; the Conway River and the Menai Straits were spanned a second time, and in 1849, a continuous line of railway was completed between London and Holyhead, by private capital, three-and-twenty years after the continuous line of road had been constructed by direction of the State and principally by grants of public money. The conveyance of the Irish mails was then retransferred from Liverpool to Holyhead, and the large and powerful packets of the Government, and of the Company which had carried the night mails under contract for the previous ten years on the Liverpool line, were appropriated to other duties.

It is not easy, from the Parliamentary returns, to arrive at the exact cost of maintaining the service between Great Britain and Ireland prior to its concentration at Holyhead, on the completion of the railway to that place. In addition to the principal postal services with Dublin, two other lines of mail communication had for many years been carried on by Government vessels; one in the north, between Portpatrick and Donaghadee, and the other in the south, between Milford and Waterford. The expense of supporting all these communications is stated at £75,000 a year.

without taking into account the original cost of the vessels, built in the royal dockyards, the interest on the capital, the annual depreciation, or the insurance. The outfit of the steam vessels provided for the Irish service appears to have cost upwards of £600,000, between the years 1820 and 1848.

During the period while these recent changes had been in progress, the Asylum Harbour of Kingstown was completed, and having ample depth of water at all times of the tide, which the harbour of Howth had not, the packet service was transferred to it. Ultimately a line of railway, 6 miles in length, connected it with Dublin.

The new Refuge Harbour at Holyhead was next decided on, with the avowed intention of providing the most perfect arrangements for the Irish Mail Service.

The only link then remaining to complete the communication with Ireland was such a superior class of vessels as the mechanical skill of the day could construct. The Government declined the offers of the former mail contractors to supply the vessels, having decided on building four of about 700 tons burthen each, fitted with engines of 350 nominal H. P. Great attention was bestowed on these vessels, and no expense was spared, with the desire of securing a result far in advance of any which had been previously arrived at. The result was universally admitted to have been a success. The 'Banshee,' built of timber, with double planking, but without frames, was a beautiful model, and of light draught of water. Her oscillating engines indicated 1.555 H. P., and her rate of speed at the measured mile on the trial trip was rather over 18½ statute miles per hour, nearly 4 miles more than had been previously attained by any other vessel. The speed of the 'Llewellyn' was very nearly as good (*vide* Appendix, p. 595), but the other two vessels, having heavier engines, were not equal to the same high rate of performance.

About the same time the Chester and Holyhead Railway Company, under what were considered the exceptional circumstances of the case, succeeded in passing a Bill through Parliament, authorising the novelty of owning and navigating steam-packets for a period of twelve years. Four vessels were accordingly provided by that Company for the conveyance of passengers. Two of these were fully equal in speed to the 'Banshee,' another was considerably less, but the fourth was admittedly a failure.

The Lords of the Admiralty, acting in accordance with the recommendation of a Committee of the House of Commons, decided, after a trial for a short time of the New Service at a heavy cost, to have it performed by contract, as had been the case for some years previously on the Liverpool line, and the tender of the former contractors was ultimately accepted. The service was to be performed at the average speed of 12 knots, or nearly 14 statute miles per hour. Four hours and forty minutes were allowed on the average for the passage of the Channel, from outside the lighthouse at Kingstown Pier to the light at Holyhead. This service lasted from May, 1850, until October, 1860, and the passages were generally performed within the stipulated time.

Having thus traced the several changes in the means of communication between London and Dublin up to the commencement of the service now in operation, it may be interesting to state the time usually occupied in the journey at various periods, in order to show the gradual improvements in acceleration, which have resulted from the continued attention of Parliament to the subject.

Before the opening of the new turnpike-road by way of Shrewsbury to Holyhead, and of the establishment of steam mail packets, the communication with London was attended with so much uncertainty, that it would be difficult to give any accurate estimate of the time necessary for the journey. Travellers in those days thought themselves fortunate, if they accomplished the distance within four days. But after the opening of that road, and the establishment of steam vessels, the average time occupied in the transmission of the mails was reduced to about forty-three hours: letters posted in London on Monday being considered as due in Dublin on the following Wednesday evening. The adoption of Liverpool as the principal packet station, and subsequently, the opening of the railway from thence to London, shortened the time for the transit of letters to twenty hours, so that letters reached either capital in the evening of the day following that on which they were posted. Within a few months after the complete restoration of the mail service to Holyhead, the time allowed for the transit of the mails was reduced to sixteen hours from Dublin to London, and about fourteen hours in the opposite direction, the reason for the difference being, that the service from Ireland was timed with sufficient margin for the contingencies of the Channel passage, to insure the arrival of the mails so as to allow of their being forwarded by the trains appointed for the ordinary English services; while for the down mails, the packets waited the arrival of the train at Holyhead from London, and invariably proceeded to sea as soon as the mails and passengers were embarked, so that generally, there was an advantage in time in the journey to Dublin. Great however, as was the improvement thus finally effected, it was impossible to afford the public the advantage of the entire day for completing their correspondence in one capital, coupled with a morning delivery in the other, so long as the transit occupied from fourteen to sixteen hours, to which must be added the time required for sorting the letters, after their arrival at the respective post-offices. The night service was therefore necessarily divided into two parts. First, an early despatch from the one end of the line, accompanied with an early morning delivery at the other; and the second, a late, or night despatch from the one capital, coupled with a late, or afternoon delivery in the other.

The Directors of the Company into whose hands the mail service between Holyhead and Kingstown had been intrusted, soon turned their attention to the subject, with the object of proposing further improvements, to be effected by the substitution of special express trains for the Irish service, in place of the ordinary trains, which were timed more in reference to the requirements of the English mails; and, secondly, by the employment of larger and more powerful steam-packets. Considerable doubts were at first expressed, as to the practicability of running trains with safety, the starting of which was to depend on the arrival of the packets at Holyhead. But the public loudly demanded more commodious vessels. Meetings were held in London, which were attended by the most influential persons interested in the question, who warmly approved of a plan then submitted for consideration, of a vessel of great size and power, which the projectors anticipated might attain the extraordinary speed of 25 statute miles an hour. Meetings of the commercial interest were also held in Dublin, to urge forward the adoption of any feasible measure of improvement, in the postal and passenger arrangements, for communication between Great Britain and Ireland. A plan was soon after submitted to Government, proposing a new service between London and Kingstown, the entire distance to be performed under ordinary circumstances in eleven hours. Express trains were to be appropriated exclusively for the Irish service, completing the land journey in six hours and forty-five minutes. For the Channel part of the service, steam vessels were proposed, 300 feet in length, with sufficient engine power to attain the speed on trial, of 20 statute miles an hour, so that the passage of the Channel could be made under favourable circumstances, in three hours and a half. The ship-builders and engineers who were consulted unhesitatingly stated that such a result was practicable.

A Committee of the House of Commons was appointed in the following year to inquire into the subject; and their report strongly recommended that the improved class of vessels should be provided, and that the speed on the railway should be accelerated, so that the mails, instead of requiring the average of fifteen hours between London and Kingstown, might be conveyed in eleven hours, as had been proposed. The Committee further recommended to the favourable consideration of the Government, the plan and estimates of the class of vessel contemplated, as able to attain a speed of 25 statute miles an hour, but to be employed only in day-light; their advocates having expressed the opinion, that they could not be safely used at night. This objection, in addition to the great cost of the vessels, estimated at £180,000 each, no doubt caused that plan to be rejected.

The London and North-Western Railway Company, and the City of Dublin Steam Packet Company, having agreed to united action, passed a Bill through Parliament, in 1855, to sanction and facilitate their arrangements.

The Government then made a communication to the Companies, as to the requirements of the Post Office, for two services, one by day and the other by night, to be completed in half an hour less time than that which had been already proposed, and this to be guaranteed under heavy pecuniary penalties for every minute of excess, arising from causes even beyond control. The Companies agreed to undertake this service, but altogether declined to submit to penalties for loss of time arising from fogs, or other causes wholly beyond their control. The subject having been allowed to lie dormant for another year, the Members of Parliament for Ireland collectively urged on the Prime Minister so forcibly the expediency and necessity for providing for the improved means of communication at the public expense, as had been formerly done when the new Holyhead Road and Telford Bridges were constructed, that the matter was at last taken up seriously and the Government agreed to carry into effect the plan recommended in 1853, and which eventually received the cordial approval of the Lords of the Treasury.[1]

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[1] Extract from Treasury Minute, dated October 19, 1855.

"My Lords have before them a private Act, passed in the last Session of Parliament, intituled, 'An Act for improving the Postal and Passenger Communication between England and Ireland, and for authorising Arrangements between certain Companies in England and Ireland in relation thereto, and for other Purposes.'

"By this Act the London and North-Western Railway Company, the Chester and Holyhead Railway Company, and the City of Dublin Steam Packet Company, are empowered to provide and use such steam boats for the conveyance of mails and passengers between Holyhead and Kingstown or Howth as they shall think fit; and it is also provided by the 18th section of the said Act as follows:

"'It shall be lawful for the aforesaid Companies from time to time to make and enter into and carry into effect any agreements and arrangements with Her Majesty's Postmaster-General, or with the Lords of the Admiralty, in reference to the conveyance in their steam boats of Her Majesty's mails or post letter-bags between Holyhead and Kingstown or Howth: Provided always, that, until an agreement or arrangement for the purposes hereinbefore in this clause mentioned shall have been so made and entered into, none of the powers by this Act granted shall be exercised by the said Companies, and that, unless such an agreement or arrangement shall have been made and entered into on or before the first day of May, one thousand eight hundred and sixty, it shall not be lawful for the said Companies, in pursuance of this Act, to exercise any of the powers granted thereby, and such powers shall thereafter cease and have no effect.'

"My Lords fully recognise the main motive which the Legislature had in

The main provisions of the new postal contract were, first, that the entire distance between London and Kingstown was to be performed in eleven hours (eleven hours and a half being allowed to Dublin), assigning four hours for the sea passage, subject to fines

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passing this Act, and in extending, in the respects therein contained, the powers and functions of the three existing Companies referred to. That motive was undoubtedly the hope that, by the combination so created, a more efficient steam boat service would be established between Holyhead and Dublin, thus connecting England and Ireland by the shortest possible passage, and in the shortest possible time, with a view to their postal and passenger communication. But so far did the Legislature recognise in any such arrangement the paramount importance of the postal service, that the clause already quoted was introduced into the Bill, by which the powers granted under it should only take effect in the event of the united Companies being able to make an arrangement with the Postmaster-General or the Admiralty for the conveyance of the mails.

"While, however, my Lords regard this as being the main object of the Act, and the one which the Government is officially called upon to take into its consideration, they by no means desire to leave out of view, in connexion therewith, the enormous social and political advantages which may be expected to be derived from such an improved communication between the two countries as the progress of art and science entitle the public to look for. Nor can my Lords leave out of view the great advantage and convenience which such an improved service would confer upon Irish Members of Parliament whose public duties necessarily lead to their frequent passage between the two countries, and who are entitled to expect every fair facility for that purpose.

"My Lords desire to know if it would be practicable—

"1. For a mail leaving London at a convenient hour in the morning to arrive in Dublin in time for the departure of the evening mails, and also for a delivery in Dublin the same night.

"2. For a mail leaving London in the evening at the usual time of departure to arrive in Dublin in time for the day mails from Dublin, and for a convenient morning delivery in Dublin.

"3. For a mail to leave Dublin in the morning at a convenient hour after the arrival of the night mails from the provinces in time to reach London for the departure of the evening mails, and for a late delivery that night.

"4. For a mail to leave Dublin in the evening, after business hours, and to arrive in London in time for an early delivery, and for the day mails out of London.

"If such arrangements shall prove to be practicable, then my Lords would be prepared to incur a considerable increased expenditure in order to secure them.

"In that case, in the majority of instances, the Irish postal service both ways would be advanced by periods varying from six to twelve hours, and in many cases, practically for business purposes, twenty-four hours, would be saved in replies, besides which the most perfect passenger accommodation would be secured. A mail would leave from each end at convenient hours, morning and evening, and, occupying only eleven hours, would arrive also at convenient times, and such as would enable passengers to pursue their journey forward without stoppage. For example, letters and passengers leaving London in the morning would arrive in time for the night trains out of Dublin, and by midnight of the same day, or shortly after, would reach all the chief cities in the provinces; and letters and passengers leaving London in the evening, would reach Dublin in time for the departure of the morning trains out of Dublin, and would arrive at all the chief cities in the provinces a little after noon on the following day; so also, letters and passengers leaving Dublin in the morning would arrive in London in time for the Continental and other mail trains the same night, and those leaving Dublin in the evening would arrive in London in time for the departures of the mail day trains. For some great and decisive advantages, such as these, to be enjoyed by the public, would my Lords feel that they were justified in incurring a material increase on the present expenditure of public money."

for loss of time, unless arising from weather, or other causes beyond control; secondly, that four steam packets should be provided, each 300 feet in length, and 1700 tons burthen builder's measurement, with engines of 600 nominal H.P.; thirdly, that express trains should be appropriated exclusively to the Irish traffic; and fourthly, a morning and evening departure from each capital. The Improved Service was arranged to be commenced in January, 1861, two years being allowed by the contract for building the vessels.

To accomplish what had been proposed, and fully to realise the expectations of the public, was naturally a subject of no small anxiety to those on whom the responsibility devolved of providing vessels so much in advance of any which had yet been built. It was not a mere question of speed at the measured mile in Long Reach, or in Stokes Bay; that had been shown to be practicable, by the great success of the Royal Yacht, which attained the unprecedented rate of speed, at the trial trip, of 19⅓ statute miles per hour (*vide* Appendix, p. 595); the difficulty was, to maintain such a rate of speed in severe weather, and under the disadvantageous circumstances which must so often occur in the passage of the Channel four times every day in the year, as to insure comparative regularity in the due performance of a mail service, with but very small margin for contingencies at sea. With the object therefore of insuring this result, it was ultimately decided to increase the size of the vessels to 2,000 tons, and that of the engines in like proportion. Designs were received from the most eminent builders in England. Those submitted by Messrs. Laird, of Birkenhead, and Mr. Samuda (M. Inst. C.E.), of London, were adopted. Messrs. Ravenhill, Salkeld, and Co., supplied two pairs of engines, and Messrs. James Watt and Co. the other two pairs. The dimensions and general arrangements of the four vessels are so nearly alike, that the following description of one, the 'Connaught,' will be sufficient for all. This was built by Messrs. Laird, as well as the 'Ulster' and the 'Munster;' the fourth, the 'Leinster,' was built by Mr. Samuda.

The ships are built of iron. The length between the perpendiculars is 334 feet; the beam is 35 feet, and depth 21 feet. The keel is formed of a centre keel plate, 3 feet deep and ⅝ inch thick, with two bars, 9 inches deep by ⅝ inch thick, on each side at the bottom; these five plates, with the two garboard strakes, ⅞ inch thick each, are secured together with iron bolts riveted and countersunk. On the top of the centre keel plate, two angle iron bars are riveted, 5 inches by 4 inches by ½ inch, and to these angle irons, and to the angle irons on the top of the floorings throughout the entire length of the vessel, as far as the fine ends will allow, is riveted a strong plate, 4 feet wide amidships, and 2 feet 6 inches wide at the ends. There are also two very strong box keelsons, secured on the floorings at each side of the keel, and another in each bilge. The general framing of the ship and the outside plating are done in the usual way, care being taken to have everything well put together. The engine beams, paddle and spring beams, and all other beams for the main and lower decks, are of iron. Timber has been used only for the decks and cabin fittings. There are nine principal iron water-tight bulkheads, which not only provide for the safety of the ship in case of accident, but add greatly to her strength in a sea-way. The bulwarks are of iron plates, in continuation of the sides of the vessel to the rail, and without any break for gangways, such not being required for landing, either at Holyhead, or at Kingstown. To give additional strength in the centre, where the weight of the engines, wheels, and boilers, has to be carried, the insides of the paddle-boxes are also formed of iron plates, continued from the sides and bulwarks of the vessel, with a strong bow girder, formed of an iron plate 15 inches broad and $\frac{3}{4}$ inch thick, so as to provide ample means of resistance to the severe shocks which these long vessels must encounter in rough seas, when driven at such a high rate of speed. The gunwale is formed of angle iron bars, 4 inches by 4 inches, riveted to the sheer strake and to a plate which is riveted on the top of the beams. At a distance of about 15 inches from this, an inner angle bar is riveted, against which the wooden waterway is fitted, so as to leave the outer part, between this and the gunwale, to form a drain to take the water off the deck, and to discharge it through the scuppers. This arrangement, which was introduced by Mr. Laird, has been found very convenient, in freeing the decks quickly from water. These iron gunwale plates are 5 feet wide by $\frac{3}{4}$ inch thick amidships, tapering gradually to about 2 feet 6 inches by $\frac{1}{2}$ inch at the ends, with a system of diagonal tie plating from side to side, securely bolted or riveted to the deck beams. Between the paddle-boxes, an upper deck, about 50 feet in length, has been placed. It is laid on iron beams well secured, and being provided also with diagonal tie plates, it further adds to the strength amidships; though the primary object was for the more rapid embarkation and landing of passengers and luggage at times of low water, both at Holyhead and at Kingstown. It also forms an agreeable promenade for the passengers in moderate weather. The wheel and the binnacle are placed on this upper deck, so as to allow of the commander and the officers being near to the men engaged in steering. All difficulty is thus avoided in passing the word, a distance of nearly 200 feet, as would have been necessary, in the ordinary way. The entire of the main deck, from the foremost funnel to the bows, is covered over by a hurricane deck formed with angle iron beams, 5 inches by $2\frac{1}{2}$ inches, extending from the rail at each side, and boarded over with planks 1½ inch thick, leaving when at sea but one small opening round the foremast. This construction has been found of great advantage in throwing off the seas, which previously to the vessels being thus protected, occasionally in heavy weather caused damage to the skylights and upper works. The weight of so large a piece of work, about 140 feet in length, is considerable, and increases the immersion of the vessel forward; but this has been amply compensated for, by the security afforded when pressing at a high rate of speed in tempestuous weather. There has not been the slightest damage to any of the vessels, during the last two years, since they were completely provided with this excellent protection. The plan was copied from a small vessel, the 'Menai,' fitted out in Liverpool for the River Plate in 1854.

The engines for all the vessels are on the oscillating principle. In the two pairs made by Messrs. Ravenhill, Salkeld, and Co., for the 'Leinster' and the 'Connaught,' the cylinders are 98 inches diameter, with a length of stroke of 6 feet 6 inches; the air-pumps are 54 inches diameter, with a stroke of 2 feet 6 inches. The eight boilers are multitubular, four being at each end of the engine-room space, arranged in pairs, with one funnel to each pair. There are five fire grates in each boiler, 3 feet 1 inch wide, with bars 5 feet 6 inches long. The boilers being placed lengthways in the vessel, the firing space, which is 11 feet wide, is in the centre. The entire extent of the grate surface in the eight boilers is 677 square feet; and the heating surface measures 19,700 square feet. The bunkers are small, being made to contain only one day's coal, as the vessels can be supplied either at Holyhead, or at Kingstown, during the interval between their arrival and departure. The space occupied in the length of the vessel by the engines and boilers is 108 feet, and this has been subdivided, by iron watertight bulkheads, into three compartments, an arrangement suggested by Mr. Laird, and which has been found most beneficial in giving strength in a part of the vessel which might otherwise have been weak, and unequal to the severe strain of the powerful machinery working in the heavy sea-way of the Irish Channel. The wheels, which are constructed on the feathering principle, with fourteen floats each, are 31 feet in diameter at the outside of the floats, or 27 feet to the centre of axis; and each float is 12 feet long by 4 feet 4 inches broad. On the trial trips, the engines worked at the rate of 25½ revolutions per minute, under a steam pressure of 25 lbs. per square inch. The mean of the runs of the 'Leinster,' at the measured mile in Stokes Bay, was at the rate of 20½ statute miles an hour, a greater speed, by upwards of one mile an hour, than had been previously attained by any other vessel. The Connaught,' when subsequently tried at the measured mile in

Stokes Bay, attained a higher result, the mean of her runs showing the speed of 20¾ statute miles per hour. (*Vide* Appendix, p. 595.)

The 'Ulster' and the 'Munster' were built by Messrs. Laird, on exactly the same lines as the 'Connaught.' The engines of these vessels were constructed by Messrs. James Watt and Co., of Soho, the same establishment from whence the engines proceeded for the first steam vessels built for the Post Office for the performance of the Holyhead Mail Service. Boulton and Watt would have been somewhat surprised, if it could have been foretold, that their successors would have been called on to construct engines tenfold the size of what they had made, to be placed in vessels tenfold the tonnage of the 'Royal Sovereign' or the 'Meteor,' and for the same line of postal communication. The general arrangement of the engines in the 'Ulster' and the 'Munster' is nearly the same as of those in the 'Leinster' and the 'Connaught.' The cylinders are, with a length of stroke of 96 inches in diameter, 7 feet. The wheels are 33 feet in diameter over all. The boilers have each six fire-places, 2 feet 6 inches wide, and the bars are 5 feet 6 inches long, giving in the aggregate as large an extent of grate surface as in the others. The area of the heating surface is 18,033 square feet. One funnel is used for the four boilers of each compartment, and as the coals are carried on the top of the boilers, the entire space occupied in the ship by these engines and boilers is but 102 feet. These engines were erected on board the vessels in the Liverpool Docks. There is not any measured mile at that port for testing speed; but from a return supplied by Messrs. Watt and Co., of observations made on several trips, the rate attained appears to have been 17½ knots, or 20·3 statute miles per hour, and the average performances of the 'Ulster' and the 'Munster,' contrasted with the average performances of the other vessels, fully proves, that this in no degree overrates their speed, when going under the usual conditions of a trial trip.

The internal arrangements of the vessels were planned with the object of providing for the comfort and accommodation of the public, in the way best calculated to mitigate, and as far as possible to prevent, the sufferings so usually inseparable from the passage of the rough Irish Channel. For although the talented builders endeavoured to design a form which should be easy in a sea way, both they, and those for whom they were building, were well aware, that it was utopian to expect, as many appear to have expected, with ships of even their large dimensions, a uniform horizontal position in tempestuous weather. Enlarged size has no doubt, in many cases, lessened the motion at sea; but the chief advantage in this instance is that, it has afforded the means of providing reasonable accommodation for many passengers,—a want which had been so much felt with the previous smaller class of packets. The saloons and cabins in the new vessels are large, lofty, and well ventilated. The principal one is upwards of 60 feet in length, by 17 feet in breadth, and 9 feet 6 inches in height. On each side of this saloon there are state-rooms, with several berths, or sofas. The ladies' saloons and cabins, which are entered from a large deck house by a separate staircase, are provided with upwards of forty sofas and berths, independent of the accommodation in the deck saloon and in the adjoining state-rooms also on the main deck. First-class passengers have excellent sleeping cabins in other parts of the ship, and there are also two commodious deck cabins, one of which is appropriated as a smoking-room. The cabins for the second-class passengers are placed forward. Throughout the whole of the communications which took place between the builders, the engineers, and the Directors of the Company, the most perfect concord prevailed; all parties appearing to be actuated by the desire to produce vessels and machinery in every way calculated to fulfil the high expectations which so much public discussion had raised.

A better opportunity could not have been desired for attaining a good result, than the Holyhead and Kingstown mail line. There was sufficient depth of water at all times of the tide, with no natural obstruction to the navigation of the Channel, and the short distance needing no great weight of coal, and no cargo being carried, the vessels would at all times have very nearly the same uniform immersion. Besides, the vast importance of the communication justified an expenditure for the mail service, which could not be undertaken as a commercial speculation, to be remunerated solely by the conveyance of the traffic. All these advantages united, afforded an unprecedented opportunity, which those engaged in the work fully appreciated, and they endeavoured to make the most of it. It is due to them to state, that after the contracts had been entered into, every suggestion made during the progress of the work, with the desire of providing further improvements as to strength, or accommodation, was at once adopted though attended with increased cost. The result proved that the unbounded confidence which was placed in the contractors, by the Directors of the Company, was well deserved.

The cost of the four ships to be provided, in accordance with the contract, was £75,000 each. The actual cost has, however, greatly exceeded the amount agreed to be expended by the Company, in consequence of the size of the vessels having been enlarged to upwards of 2,000 tons, and the engines in about the same proportion; a change which has obtained increased accommodation for the public, and probably a superior performance of the vessels at sea.

One of the principal peculiarities, which render these vessels of so unique a class, is the post-office fitted for sorting letters during the passage. The space occupied for this purpose extends across the entire breadth of the vessel, and for the length of 30 feet, between the first and second class cabins. It is divided into two rooms, one for letters, and the other for newspapers. In these rooms the sacks are opened, the contents taken out and arranged, by eight, or ten sorters, under the direction of a head superintendent. The letters are stamped with the post-office packet brand, the postage label cancelled, and all the operations completed, so that the letters are ready for delivery, or to be forwarded to their destination, on the arrival of the vessel at Kingstown. About two hours are thus saved in the transmission of the mails, in consequence of their being made up on board, instead of after their arrival at the General Post Office in Dublin. Besides the gain in time thus secured for postal purposes, the main object to be attained was regularity; while for passengers, accommodation was perhaps even more to be valued than extreme speed. To fulfil all these conditions, it was necessary to have very large vessels; such only obviously allowing the requisite extent of accommodation, and experience had shown that the larger the vessel, when provided with adequate power, the less was the difference in the length of the passage at sea caused by severe weather.

The contract with the Postmaster-General had appointed January, 1861, for the commencement of the Improved Service. But the vessels being in readiness some months sooner, it was commenced, by mutual agreement, in October, 1860, and has since been continued without interruption. When two of the vessels, the 'Leinster' and the 'Ulster,' were completed, and ready for duty, it was thought advisable to make a trial with them, by way of practice, in the performance of the old contract. Each performed the distance between the lighthouse on Kingstown Pier to the lighthouse at Holyhead, upwards of 65½ statute miles, in nearly the same time on the average, namely, the 'Leinster' in three hours and thirty-one minutes, and the 'Ulster' in three hours and thirty-two minutes, being respectively thirteen and twelve minutes less than the shortest monthly average of the 'Banshee' in 1848-49, and twenty and nineteen minutes less than the 'Llewellyn,' when the distance between the lights was one mile less than in 1860—the Holyhead breakwater not having been then in existence.[1] The gain in speed realised by the new vessels was therefore at the rate of from 1·2 to 1·7 mile per hour.

Before however giving an account of the actual performance of the contract for the Improved Service, which is one combining the land journey with the passage of the Channel, inclusive also of the time occupied in the transfer of the passengers, mails, and luggage, between the packets and trains at the Holyhead jetty, it will be right to state the means agreed to be provided by Government for the berthing and accommodation of the large vessels at Kingstown and at Holyhead. This subject had from the first engaged the anxious attention of the promoters of the Improved Service, for they were well aware, that any attempt to convey the mails with regularity between London and Dublin in eleven hours and a half as proposed, would be wholly unsuccessful, unless landing piers were provided at both sides of the Channel, easy of access in all weathers, and such as would allow of the berthing of the vessels, and the transfer of all on board, with the utmost economy of time. A stone jetty, perfectly adapted to meet all these requirements, had been commenced in Kingstown Harbour by the Board of Works, in accordance with the plans of the late Mr. Barry Gibbons, in 1852, provision having been made for the continuation of the line of rails, so as to connect it with the Dublin Station. The late Mr. Rendel having stated his objections to this pier, both as connected with the safety of the vessels and the convenience of the public, the work was ordered by Government to be suspended, and it was not again resumed, until after a full inquiry by a commission of naval officers appointed for the purpose by the Admiralty. Their report was so decisive in favour of the pier as originally designed, that the work was immediately resumed, and it was completed and ready for use in good time. After a daily experience of nearly three years, it is due to the memory of Mr. Gibbons to testify, that this packet pier has fulfilled to the utmost the most sanguine expectations of all who were qualified to give an opinion on the subject. The packets usually arrive at the west side, where the passengers land under shelter, and taking their places in the railway carriages, are conveyed to Dublin in fifteen minutes. The packets are afterwards backed round the semicircular end of the jetty to the east side, where they remain in readiness for the outgoing mails. They lie in still water at all times.

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[1] The courses are laid down on the plan of Holyhead Harbour attached to this communication.

The new harbour at Holyhead, which was sanctioned by Parliament with the twofold purpose of providing for the mail packet service and for refuge, had made considerable progress before any definite plan was arranged for the primary of these objects. Mr. Rendel, a short time before his last illness, had been in communication with the steam and railway companies, to ascertain their views as to the arrangements which would best suit the Irish service; but requiring that the position should be in a depth of water sufficient for the accommodation of the Trans-atlantic vessels, it being at that time anticipated that Holyhead would be fixed as their port of call. The death of Mr. Rendel soon afterwards left the decision in the hands of his successor, Mr. Hawkshaw, (President Inst. C.E.,) who renewed the inquiry with a similar limit as to choice of position. The result of his investigation was a plan for very extensive piers, with quays upwards of 3,000 feet in length, which met with the approval of all the parties whom he consulted, and he omitted none who were interested in the subject. These plans, the estimated cost of which was £425,000, were sanctioned by Government and by Parliament in 1858. Provision having thus been agreed to be made for the safe, easy, and expeditious berthing of the large vessels, near the entrance of the new harbour, and for convenient communication with the railway and trains, the united companies entered into the joint contract with the Postmaster-General for the performance of the entire journey between London and Kingstown pier in eleven hours, guaranteed under penalties for excess of time, unless arising from causes beyond control. These penalties were not, however, to be put into operation, as proposed on the part of Government, until the piers which had been agreed to be provided were completed. The vessels being ready, it was arranged by Government, that the service should be commenced and carried on, as well as the circumstances would admit, without penalties, so long as the vessels and trains were confined to the use of the timber-jetty, constructed at the end of the old packet quay for temporary use, pending the completion of the permanent works. It will thus be seen, that there is yet to be provided one link for the chain of the improved communication between London and Dublin; a most important link which had been very carefully considered, and specially stipulated for, as essential to the full accomplishment of the plan which had been proposed for adoption.

It remains now to give some information as to the manner in which the new service has been performed since it was commenced in 1860. From what has been already stated, with regard to the speed of each of the vessels on their trial trips, when, as is usually the case on such occasions, the utmost power of the engines is exerted during the short time required for the run of a few miles, it may be readily seen, that for actual daily duty, the difference between the four vessels is inappreciable, a matter of paramount importance to a mail service. The extreme difference in the rate of speed on trial appears to have been about half a mile an hour, which would add but six, or seven minutes to the passage between Holyhead and Kingstown, taking the present course at 57 knots, or a little over 65½ statute miles; the extension of the great breakwater having added more than a knot to the distance given in the Admiralty Returns, as having been performed by the 'Banshee,' the 'Llewellyn,' and other packets in 1849–50. A speed of 17½ knots, or 20 statute miles per hour, on the trial trip, allows a safe margin for making the passage commonly in four hours, the time proposed by Government; but this large margin has not in practice been found too much. Again, it may be observed, that there is a considerable difference in running a few times by the measured mile, when all is tasked for a short time to the utmost; and making a single complete passage of the Channel, even under favourable circumstances. Thus, while the 'Connaught' attained a speed of 20¾ statute miles an hour on her trial trip, her shortest passage of the Channel occupied three hours and fourteen minutes, being at the rate of about 20 miles an hour. The shortest passage of the 'Leinster' was made in three hours and twenty minutes; that of the 'Ulster' in three hours and eighteen minutes, and of the 'Munster' in three hours and twenty-six minutes. But the average performance of the vessels for the two years and five months during which they have been on service is still closer. Inclusive of all passages made in fogs, gales, &c.,

			h.	m.
The 'Connaught' made	1,064	in the average time of	3	51·5
The 'Leinster' . .	919	„	3	52·5
The 'Ulster' . . .	925	„	3	55
and the 'Munster' . .	920	„	3	58·1

So close a performance by the four vessels, not identical and not all from the same builders and engineers, could scarcely have been anticipated. The longest passage made in the severest gales has not exceeded five hours and forty minutes, and one vessel only has been that length of time on but two occasions. The previous packets were retarded by the weather to a far greater degree. The 'Banshee' has taken nearly eight hours to cross the Channel; the 'Llewellyn,' the 'Caradoc,' and the 'St. Columba' still more. Nearly four thousand passages have been already made without collision, except on one occasion, which happily was not attended with very serious consequences. Experienced naval officers anticipated frequent and serious disasters, but the rate of speed, 16 miles an hour, though high for night-work, does not appear to have been too high for safety. The sense of greater responsibility, and the larger number of men engaged in the navigation and management of the vessels, must naturally induce additional precaution, as well as afford the means of guarding against danger. The facility with which these large vessels are handled and brought alongside the jetties is remarkable. The practised skill of the officers, and the quickness with which the engines are managed, frequently succeed in getting the vessels alongside, in making them fast, establishing the means of communication with the shore, and in landing the mails in three, or four minutes.

The consumption of coal in the first few months was considerably in excess of the quantity originally estimated. Steam of from 25 lbs. to 28 lbs. pressure was then used, which not only required much extra coal, but severely taxed the durability of the boilers. Arrangements were therefore made to reduce the consumption to the amount stated in the estimates submitted to Government, on which the contract was founded. The result has been satisfactory, while the additional time occupied on the passages is but a few minutes, and they are still made on the average within the time allocated to the sea service by the proposal of Government. The necessity of laying up the vessels more frequently for repairs has been also diminished, which is a matter of much importance, as they are of so unique a class, that in the event of more than two being laid up at the same time, it would be impossible to obtain an efficient substitute, and therefore, the postal service might be exposed to some danger of interruption, if such circumstances were to continue for any length of time. The engines in the 'Ulster' and the 'Munster' were provided with superheaters, but experience has not shown any advantage resulting from their use, either as reducing the consumption of coal, or tending to a superior performance. These vessels have made in the aggregate 1,845 passages, in the average time of 3 h. 56 m., and have consumed 30 tons 7 cwt. on the average of each, inclusive of the quantity required for raising steam, which is very considerable. The 'Leinster' and the 'Connaught,' without superheaters, have made 1,983 passages, in the average time of 3 h. 52 m., and have consumed (inclusive of raising steam) on the average, 30 tons 1 cwt. of coal.

No break-down has taken place with any of the engines. On two occasions some derangement occurred with the wheels. Very constant attention is given during each 'rest' after the usual term of duty, to the machinery and the boilers, so as to prevent the necessity of extensive repairs.

The principal trouble has arisen from the difficulty which appears to be experienced, in obtaining sufficiently sound forgings for the large intermediate air-pump crank shafts. As a precautionary measure, two duplicate shafts fitted with cranks had been included in the original order, one suitable for either pair of engines from each firm, so that no time might be lost in replacing one, if at any time it was found to be defective, or appeared to be doubtful. This was no needless precaution, as within the first year it was found necessary to condemn two shafts, and to use the duplicates, and the vessels were ready within the week for service instead of being laid up for months. Two new spare shafts were immediately again ordered, and these have since been required; and another of steel, made by Mr. Krupp (of Essen), is also now in use. Thus, within the space of two years and a half, five of these costly pieces of work have been already condemned. It is justice to the makers of the engines to state, that they have met the case in the most satisfactory manner. No failure has hitherto occurred with any of the shafts supplied by the Mersey Steel and Iron Company, and they have done their full share of duty. Very great exertion was made by that establishment on one occasion to prepare a forging within the short space of three weeks, to replace one under peculiar circumstances, which rendered the utmost expedition important.

With regard to the ships, it is very satisfactory to be able to state, that no repairs have so far been needed. They are now in as perfect a condition, after the performance of their severe duty, as when they commenced in 1860. The frequency of docking, for the purpose of cleaning and coating, has afforded constant opportunity of examination, but painting only has been found necessary.

To maintain speed, it is obviously indispensable to keep the bottoms of the vessels clean; but as no docking accommodation has as yet been provided at Holyhead, and it being objectionable to remove the vessels from the station to the graving-docks of other ports, if possible to avoid doing so, the experiment of employing divers, while the vessels lay alongside the jetty, was tried last summer, and with some success. The growth of marine vegetation, and the adhesion of marine animals, which take place rapidly in the summer months, were prevented to a considerable extent.

The Author, connected as he has been with the sea part of this service, has thus endeavoured to give the information which constant and anxious watching over it from the commencement has enabled him to do. He postponed submitting to the notice of the Institution any communication on the subject, until a sufficiently-prolonged experience might justify the expectation of a continuance of the same performance. It would be wrong, however, to close this Paper, without referring to the admirable performance by the London and North-Western Railway Company, of the land portion of the journey from London to Holyhead; the punctuality of the arrival of the trains on the jetty there, the speed maintained, and the excellence of the carriages supplied, are the subject of universal approval. Further improvements at present unthought of may no doubt be yet brought into operation; but whatever changes may take place, there would appear no reason for anticipating that the communication by way of Holyhead will ever cease to be the best for postal purposes, and to be preferred by the travelling public, so long as the entire distance between London and Dublin can be accomplished within eleven hours and a half.

APPENDIX.

PARTICULARS OF TRIAL TRIPS.

—		Banshee.	Llewellyn.	Victoria and Albert.	Leinster.	Connaught.
When tried		10th Jan., 1848.	15th May, 1848.	23rd July, 1855.	26th July, 1860.	27th Sept., 1860.
Where tried		Long Reach.	Nore and Mouse.	Stokes Bay.	Stokes Bay.	Stokes Bay.
Draft of Water	Forward	8 ft. 8 in.	8 ft. 6 in.	13 ft. 10 in.	12 ft. 2½ in.	12 ft. 9 in.
	Aft	9 ft. 0 in.	9 ft. 2 in.	14 ft. 0 in.	13 ft. 2½ in.	13 ft. 2 in.
Area of Midship Section		192 feet.	185 feet.	401 feet.	336 feet.	341 feet.
No. of Revolutions		30·5	28·5	25·4	26·25 mean.	25·5
Pressure on Safety-valve		19 lbs.	20 lbs.	23 lbs.	25 lbs. by gauge.	26½ lbs. by gauge.
Vacuum in Condensers		..	..	25 inches.	25 inches.	25½ inches.
Nominal Horse-power		350	350	600	720	720
Indicated Horse-power		1,555	1,890	2,980	4751	4735
Speed of Vessel—Knots		16·1	15·912	16·827	17·747[1]	18·079[1]
,,	Statute Miles	18·553	18·317	19·377	20·429	20·811

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[1] The mean of four runs.

Mr. J. Scott Russell,

Mr. J. SCOTT RUSSELL, V.P., said, the regularity in the performances of these vessels in all weathers, their close approximation with each other, and the high speed that, considering all the circumstances, had been uniformly maintained, must be regarded as most satisfactory; for with so high a rate a serious mistake in any of the vessels must have led to a marked loss of speed. A vessel built on suitable lines, and 320 feet long, ought to attain a speed of between 20 and 21 miles an hour, and these vessels had, it appeared, done all that could be expected in bad weather, as well as maintaining the speed due to their length. This result he considered peculiarly gratifying, inasmuch as he was many years ago examined before a Committee of the House of Commons, as to whether a velocity of 20 miles an hour, then thought to be impossible, could be obtained, or maintained, between Holyhead and Dublin, by vessels of any conceivable dimensions; and he could only succeed in convincing the House that such a result could be obtained, by repeating the same evidence before several Committees. At last, however, it was accomplished: and shipbuilders began to consider, that, with adequate power, 20 miles an hour was what a properly designed vessel ought to do.

Although the particulars given were interesting and valuable, there were several points on which further information was desirable, to make the Paper complete; as, for instance, in each case, the area of the midship section immersed, the displacement of the ship, the extent of immersed skin, and the proportion of power given out by the engines, when a given amount of performance was attained by the vessel. These were a few technical points, which Engineers would like to have, in order to see what difficulties had been overcome, and how they had been surmounted.

Mr. SAMUDA stated that, on the trial trip of the 'Leinster' in Stokes Bay, the area of the midship section was 336 feet, the displacement was 1,900 tons, the average draught was 12 feet 9 inches, the steam power was 4,751 indicated H. P., and the speed was 17¾ knots, or 20½ miles per hour. Taking these particulars, the co-efficient did not appear high: but the vessel went through the water with very little disturbance, in fact, it scarcely raised a wave, so that as far as could be judged by ordinary observation a considerably higher performance might have been expected. Whether the great speed had anything to do with the comparatively low co-efficient, or whether it arose from the dip of the wheel, he could not say. The extreme diameter of the paddle-wheels was 31 feet, the diameter at the centre of the axis was 26 feet 10 inches, the stroke of the engines was 6 feet 6 inches, the diameter of the cylinders was 98 inches, and the number of revolutions was 26·4 per minute. The engines worked very smoothly and well. The slip of the paddle-wheel during the trial of the 'Leinster' was actually 19·41 per cent.

Mr. Brereton thought it desirable to have some explanation, with regard to abandoning the use of the superheating apparatus so soon after its application, and the grounds on which it was given up. There were strong advocates for superheating, and, as far as experience went, the moderate use of it appeared hitherto to have been satisfactory.

Mr. E. A. Cowper considered, that in a Paper of this kind, full details should be given. He would be glad to know whether the cylinders and cylinder covers were fitted with steam jackets; at what degree of expansion the steam was cut off; what was the surface of the superheaters, to what temperature the steam was superheated, and how long the superheaters lasted; and what was the diameter and width of the wheels, and the size and dip of the floats.

Mr. Watson said, it had not been his purpose to enter into the engineering details of these vessels, but merely to give the results of his experience of their working. The course he pursued, with regard to the plan of vessels for the Improved Service, was this. He made inquiries as to the speed of the fastest ship then known,—the Royal Yacht,—and as soon as it was determined that this service should be established, the Admiralty afforded him every facility for ascertaining the capabilities of that vessel. The result satisfied him and his colleagues that what was desired could be achieved, by building vessels with finer lines, with less immersion, and with less midship section, than the Royal Yacht; and then by putting more power into them, a slightly higher speed might be obtained. The result had been as anticipated. The speed of the Royal Yacht was a trifle under 17 knots, and the fastest of these boats was over 18 knots, an hour. The Appendix to the Paper (page 595) would be found to contain some of the particulars asked for, in reference to two of the vessels engaged in the Improved Service, the 'Leinster' and the 'Connaught,' as well as of some others.

With regard to abandoning the use of the superheating apparatus, the Company had placed themselves unreservedly in the hands of the Engineers. Mr. Ravenhill did not recommend superheaters, but Mr. Blake (of Messrs. James Watt and Co.) was in favour of the system, and on the Company acquiescing in his advice, the apparatus was supplied. The superheating apparatus mentioned in the Paper consisted of a casing round the lower part ot each funnel, about 12 feet deep, in which were placed divisions of iron plates, which acted also as stays inside. It was found, however, after some time, that these divisions were wholly destroyed by oxidation, and some anxiety was felt lest this might cause an accident; as portions of the decayed parts of the divisions, having fallen to the bottom of the superheaters, got into the slide-valves, and materially damaged them. The great inconvenience and expense of renewing the slide-valves induced the discarding of these superheaters; and as it further appeared that economy of fuel and greater speed were rather in favour of those vessels in which they were not employed, the reasons were all on the side of abandoning the system. Besides, there was to be considered not only the question of the expense of the repairs of the slide-valves, &c., but the laying up of the vessels during the time of these repairs, as laying up one vessel out of four, with a service of four passages daily, was a serious matter. If from such causes the Company should be reduced to two vessels—as had been the case—and an accident occurred to one of those two, the mail service between England and Ireland would be jeopardized. It was most important, therefore, not to have anything connected with these ships which involved increased liability of interruption of the service.

Mr. PHIPPS thought no subject was more interesting than that of the skin resistance of vessels, as being one of the elements of calculation which limited their length; and he should have been glad if the Paper had contained details of that kind. On previous occasions[1] he had drawn attention to the singular difference in the co-efficient of the friction occasioned by water flowing through pipes, or water courses, as compared with the skin resistance of vessels. On a vessel going 12·2 miles per hour, or 17·9 feet per second, the skin resistance was shown to be about 1 lb. on every square foot, whilst in a pipe the resistance was about 2 lbs. at the same velocity. It would be useful to inquire, what was the cause of that difference. In the present case, at 20 miles an hour he calculated the friction on every square foot of the ship's immersed surface was about $2\frac{3}{4}$ lbs.; it was evident, therefore, that this was an important element in determining the best proportion between the length and the breadth of a vessel. From data in the Paper it appeared that the slip of the paddle-wheels was about one-seventh only of the speed of the vessel. This he conceived to be unprecedentedly small. It would be interesting to know whether practically the slip differed much in the feathering and the common paddle-wheels, and whether the floats of the feathering paddles were liable frequently to get out of order.

Mr. E. HUMPHRYS observed, in reference to the statement that vessels 320 feet in length might be expected to have a speed of from 20 to 21 miles an hour, that if the results obtained by these boats were compared with the Royal Yacht, it would be found that their extra length had been a considerable drawback; although he fully admitted that their performances were remarkable. The proportion between the length and breadth of the Holyhead boats was $9\frac{1}{2}$ to 1, whereas the length of the Queen's Yacht was only $7\frac{1}{2}$ times its breadth, the absolute length of the latter being 306 feet, and the beam $40\frac{1}{2}$ feet. In the absence of indicated H. P., he thought it fair to take the area of the fire-bars as representing the power exerted by the engines; as he did not believe there would be much difference in the power obtained from a given amount of fire-bar by any of the respectable makers of marine-engines. If the cube of the speed of the Holyhead boats ($20\frac{3}{4}$ miles an hour) was multiplied by the midship section, and then the product was divided by 677 feet, the area of the fire-bars in the 'Leinster,' the co-efficient of 4,480 would be obtained. In the same way, taking the speed of the Queen's Yacht at 19·35 miles an hour, the midship section as 393 feet, and the area of the fire-bars as 540 feet, the co-efficient for the 'Victoria and Albert' would be 5,272. Where then, he asked, was the advantage of the longer ship? These were interesting facts to be discussed amongst Engineers; and although the commercial value of the transaction should form one part of the inquiry, yet Engineers had to ascertain what results were obtained by increasing the power, by adding to the length of a vessel, and by giving her finer lines. Now turning to the midship section of the two vessels; in the 'Leinster,' the midship section on the trial trip was 336 feet, and the power exerted is now stated to have been equal to 4,751 horses. If the power was divided by the midship section, the result per square foot of section would be 14·1 horses. In the Queen's Yacht the power indicated on the trial trip was as nearly as possible equal to 2,980 horses; that power divided by 393 feet, the midship section on the trial trip, gave only 7·59 horses per foot of section. Where, again, was the value of the long ship? He believed that, when the length exceeded seven, or seven and a half times the beam, it was a positive disadvantage; and he disputed altogether the assertion of Mr. Scott Russell, that length only should be considered, in determining the proportions of a fast steamer.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xiv., p. 302; and vol. xvi., pp. 337 and 360.

With regard to superheaters, he had fitted a great many vessels with them, and had found that when they were made of iron their duration was about two years and a half; in the Holyhead boats they did not appear to have lasted so long. Mr. Humphrys now made them of copper a quarter of an inch thick, and steamboat companies found it advantageous to have them of copper.

The slip of the feathering wheels was about 20 per cent., taking the centre axis of the float-boards. He believed the slip of the common wheels would be found to be about 30 per cent. upon the outer circumference of the boards.

Mr. A. I. **Robertson** said, taking the midship section of the 'Connaught' at 336 square feet, the indicated H. P., at a speed of 20¾ miles an hour, at 4,730, and allowing two thirds of the indicated horse power as effective, he found that the resistance per square foot of midship section at 10 knots an hour, which was a usual standard of comparison between vessels, was 51 lbs. He expressed a hope that Mr. Scott Russell would furnish the Institution with the results obtained from the 'Great Eastern,' which he believed contrasted favourably with this.

Mr. **Hawksley** said, as this subject had engaged his attention for many years, he would venture to say a few words. During the session of 1856-57, an interesting discussion occurred "On High Speed Steam Navigation."[1] On that occasion he investigated the several properties of vessels of this description, and then submitted a rule, with some examples,[2] for ascertaining the resistance to a vessel, when moving through water at any given speed. He found by applying that rule to the vessels under consideration, that the result would be a speed of rather under 20 statute miles per hour, which agreed very closely with the speed he understood these vessels had actually attained. Since that period he had taken advantage of opportunities of practically testing those investigations in various ways, and he found they might be relied upon with certainty, within 5 per cent.

With regard to the question of the skin resistance, he disagreed with the opinion, that it was greater on the inside of a tube than on the outside; in point of fact the skin resistance was the same in both cases, and taking the speed at 10 miles an hour, or 15 feet per second, it amounted to about 25 ounces per square foot of surface. That might be taken as a practical fact, and the result was this: that in vessels of this description going at high speeds,—the vessels being of considerable length and attaining high velocity,—the midship resistance might be disregarded, and the skin resistance alone be considered. The minimum resistance took place when the length of a vessel was about seven times its breadth. If that was exceeded, the result was less satisfactory. The midship resistance, which had hitherto been generally regarded as important —and correctly so in the case of slow-moving vessels—became of no importance, and almost vanished out of the equation, when applied to a vessel of sharp lines and moving at a high velocity, and in fact the only thing to be considered practically was the amount of skin resistance. The problem was thus reduced to a simple solution: and taking that mode of calculation, of which examples were given in the discussion he had alluded to, it was possible, with regard to any of these fast-going sharp vessels,—knowing the power of the engines, and the dimensions of the vessels,—to calculate certainly within 5 per cent. the actual speed they would attain.

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[1] *Vide* Minutes of Proceedings, Inst. C.E., vol. xvi., pp. 327-370.

[2] *Ibid.*, p. 355.

Mr. Scott Russell, V.P., thought it only wanted an explanation of words to clear up any apparent discrepancies. He made some experiments twenty years ago, which first acquainted him with the true state of the facts, in regard to skin resistance and midship section. He was able to do what had not been often done in steam navigation, to tow one large steam ship by another large steam ship, with a rope, and a dynamometer; and to ascertain, before he applied the steam, how much positive, direct tractive force was necessary to draw that vessel through the water at given speeds. He then found that on a fine smooth copper bottom, with a favourable form for the speed intended, 1 lb. per foot, at 11 knots an hour, gave the measure of the resistance of the skin. The coefficient of resistance on the midship section, not being of the fine forms since used, was one-sixth part of what was called head resistance. This would lead to a conclusion similar to Mr. Hawksley's formula. The resistance of the skin was most important. As Mr. Humphrys said, it was fatal to extreme length in proportion to breadth. He did not think, however, that a little short boat, with fine lines, say with a beam of only $\frac{1}{30}$th of the length, could ever be made to go fast. He believed that an absolute length of ship was necessary to a given speed. Mr. Russell doubted whether a speed of 20 miles an hour could ever be obtained in a vessel of less length than about 300 feet, however much the midship section might be diminished, and whatever the character of the marine engine by which she was propelled. With a vessel 300 feet in length, a wide boat could be made to go faster than a narrow one. That was a direct consequence of what Mr. Hawksley had said, and was carrying out Mr. Humphrys' own conviction. The reason was,—and it was much stronger in an iron ship than in a wooden ship,—that the skin resistance of an ordinary iron ship might be as much as 2 lbs. per foot at 12 miles an hour. That accounted for the enormous quantity of power that was expended in making these long fine boats go 20 miles an hour, and he believed, that by adopting what he called the wave form of vessel, which disturbed the water to the least amount possible, the resistance of the midship section would be reduced to a surprisingly small quantity. He had found it come under one-twelfth part of the direct head resistance, and therefore he almost believed that in a proper ship the resistance due to the midship section might be got rid of altogether. For the last twenty years he had expressed the belief that the wave form would accomplish that; and he thought it was now arrived at, as all the calculations, from the data given, as to the resistance due to the skin of these vessels, showed that nearly the whole of the power was required in dragging them away from the water which hung to them.

He mentioned a curious phenomenon which he could not explain, nor had any one else, that he was aware of, yet been able to explain it. On looking along a vessel when she was going fast, a ribbon of water would be seen sticking to her, which was in a totally different condition to all the rest of the water around. In the next place it would be observed that that ribbon never changed its breadth with an alteration of the speed; that on a boat 100 feet long that ribbon became 3 inches wide, on a boat 200 feet long it was 6 inches wide, and on a boat 300 feet long it was 9 inches wide. That ribbon was in the act of being torn into shreds, and the innermost layer stuck to the boat and went with it at the rate of 20 miles an hour; then the next layer only went 19 miles an hour, and so on to the outer layer, which was still. What must be the effect of that ribbon sticking to the ship he left them to judge; but it had been considered enough to exhaust all the power of the engines. He had driven small vessels through the water with enormous power, at such a pace that they had communicated the whole of their impulse to this skin of water, and in such a manner that the water in contact with the entrance of the bow had risen up in one continuous sheet. This was a phenomenon he confessed he did not understand. It was a new state of things, and he was not prepared to say at what velocity it would be found to take place, nor what was the critical velocity at which the vessel no longer dragged its ribbon of water with it, but forced it into the air.

As to H.P. per foot of midship section for the purposes of comparison, when it was known that at 22 knots, or 26 miles per hour, the resistance on the skin would be 8 lbs. per foot, it was clear that the skin of the vessel demanded more consideration than the midship section. He hoped Mr. Humphrys would give the Institution the benefit of his data, because what arose out of this question would be important. The only fault Mr. Russell would find with the propagation of the power through the paddle wheels was, that he would have given a longer stroke, to a given diameter of paddle wheel, and that might have gained a little speed: but that was a difference of opinion to which he did not attribute much value.

Mr. WATSON remarked with regard to the length of these vessels, that the question of passenger accommodation had mainly to be considered. The space occupied by the engines and boilers was so large, that without great length there would have been insufficient passenger accommodation, and the vessels could have done little more than carry the engines. He quite agreed with what had been said about skin resistance. Some years ago he had a conversation with Mr. C. Atherton (M. Inst. C.E.) on the subject, when the City of Dublin Steam Packet Company contemplated lengthening one of their vessels, with the expectation of gaining considerably in speed, as well as in carrying capacity. Mr. Atherton was not sanguine of obtaining any great increase of speed by decreasing the immersion, from the intended extra length of the ship. The result was, that an increase of speed was obtained, but not to the extent anticipated by the Company, from the decreased immersion, and thus Mr. Atherton's views were proved to be correct.

He had been much interested in the subject of the skin resistance, feeling sure that it had a greater effect upon the speed than was generally supposed. The captains were constantly complaining, that the vessels were losing speed from fouling; therefore the ships were repeatedly docked, and when examined, it was astonishing how little there was apparently calculated materially to affect the speed, which practically corroborated what had been said with regard to skin resistance.

May 19, 1863.

JOHN HAWKSHAW, President,
in the Chair.

THE following Candidates were balloted for and duly elected:—WILLIAM NEILL and GEORGE SMITH, Junior, as Members; FRANCIS FOWKE, Captain, R.E., ALGERNON JOY, ARTHUR WILLIAM STIFFE, JOSEPH HENRY TUCK, and WILBERFORCE WILSON, as Associates.

No. 1,095.—"On the Manufacture of Duplicate Machines and Engines." By JOHN FERNIE, Assoc. Inst. C. E.

THE block-making machinery, designed by the elder Brunel for Portsmouth Dockyard, was nearly the first introduction of that system of special machines, each adapted to perform a particular operation, which may be said to have culminated so successfully in the Small Arms Factory at Enfield. Shortly before Brunel's day the factory system had been established, in which one machine shook out the impurities of the material, another spread, a third twisted, and a fourth spun; but there was no similar arrangement as applied to such refractory materials as wood and iron. In the year 1851 a great impetus was given to the extension of this system in Great Britain. It then became more generally known, that the Americans had established factories for the making of locks and fire-arms, and had, by means of the Blanchard lathe, and of a system of copying from patterns, greatly advanced in the manufacture of duplicates.

In Mr. Beamish's "Life of Sir M. I. Brunel,"[1] it is stated, that a saving was effected by the introduction of the block machinery of about £20,000 per annum; that four men, with the machinery, could make as many block shells as fifty men could produce without it, and that, in making the sheaves, six men could do the work of sixty; so that ten machine-men could do the work of one hundred and ten workmen. Another important result was that the blocks were duplicates of one another, and the parts were interchangeable.

In the year 1855 the old establishment at Enfield was broken up, and a new one was formed for the purpose of making rifles of the 1853 pattern, on the system established in America. The accounts for the year 1859-60 show, that the number of rifled muskets which had then been delivered into store was 87,405, on which there had been expended a total sum of £178,588 10*s.* 7*d.*, being at the rate of about £2 1*s.* 8½*d.* per arm; while the contractor's price for the same, at £3 3*s.* 8*d.* per arm, would have been £272,509 5*s.*; thus, a saving had been effected of £93,920 14*s.* A proper allowance for depreciation on tools and buildings was made, and no money value is claimed by the Enfield authorities on account of the arms being duplicates of one another. It is only necessary to see a rifle put together at Enfield thoroughly to appreciate the mechanical advantages of the duplicate system. Thus, the separate pieces which form the lock are picked up indifferently from heaps of such pieces, every one fitting into its place most perfectly; and a rifle, the parts of which have never been together before, is formed in a few seconds from a lot of fittings promiscuously thrown together, as any lock will fit any stock, any stock will fit any barrel, and each part, however minute, will fit any rifle. If any part be broken, or requires replacing, there is a new one which will exactly fit it, so that wherever troops are armed with the Enfield rifle, there is not any fear of a mischance through a bayonet not fitting, and the armourer's duty is confined to the exchange of a few duplicate cocks or springs; and, as it is only a system of exchange, a skilled armourer may be dispensed with. Whether serving in Canada, India, or China, the various parts of that delicate instrument can be sent from home, with the certainty that they will fit the places for which they are intended, and thus there is a great saving of time and money, and the soldier is inspired with confidence in his rifle by the knowledge that it can be quickly made as good as new. It is no part of the Author's intention to describe the machines employed at Enfield. The parts of the rifle being small, special machines are adopted. These examples are only intended to show, that the system of duplicates both cheapens and improves the manufacture of all articles to which it can be applied.

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[1] *Vide* "Memoir of the Life of Sir Marc Isambard Brunel." By R. Beamish, F.R.S. 8vo. Lond., 1862. Page 97.

Until lately, little or nothing had been done in the application of this system to the manufacturing of machines, or engines on a large scale. It is true the principle had been acknowledged, and various writers had urged the desirableness of its introduction into the railway system; but with such large component parts special machines were out of the question, and the only other possible mode was working to a correct standard. In the year 1840, Mr. Whitworth (M. Inst. C.E.), of Manchester, read a Paper at the meeting of the British Association in Glasgow "On Plane Metallic Surfaces, or True Planes;"[1] in 1851, at the Great Exhibition in Hyde Park, he exhibited a machine for obtaining accurate minute measurements by touch; and at meetings of the Institution of Mechanical Engineers at Glasgow, in 1856, and at Manchester, in 1857, he advocated the adoption of a system of measurement for mechanical engineering work, in which the inch was to be the basis, sub-divided into a thousand parts for the finer dimensions. In these Papers[1] Mr. Whitworth demonstrated, most satisfactorily, the importance of fine measurements, and by models he showed that the thousandth part of an inch was not only an appreciable quantity, but that in a great many cases that difference was what constituted a bad fit.

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[1] *Vide* "Miscellaneous Papers on Mechanical Subjects." By J. Whitworth, F.R.S. 8vo. Lond. 1858. Page 3.

The Author had long been satisfied, that the mode of taking dimensions in the workshop was far behind the times. A long and carefully graduated rule was considered the standard, and was used for setting out some of the work; but its application in the workshop was out of the question. The workman's rule was the real standard; and a bare $\frac{1}{16}$th, or a full $\frac{1}{32}$nd, of an inch embraced a very wide field indeed, extending to the shrinking on of a tire, or to the boring out of a wheel. With the sanction of Mr. Kirtley, the locomotive superintendent of the Midland Railway, the Author established a system which has, during the last five years, proved most beneficial, not only in reducing the cost of the work, but in greatly improving it, and at the same time perfecting the only plan by which all the parts of engines become duplicates of one another. At first a small machine, made by Mr. Cocker, of Liverpool, from Mr. Whitworth's gauges, was used; but it was soon found, that a larger and better machine was required. The system of end measurement with a gravity piece, as invented by Mr. Whitworth, was then adopted, and the machine first made took in 12 inches; but this also was found to be insufficient, and it was lengthened out to receive 100 inches. This machine consists of a strong bed plate (Plate 22, Figs. 1 to 7), having a V groove planed throughout its whole length. At one end there is a headstock, through which a square spindle, which fits the groove, is propelled by a hand wheel, which forms the nut of a screw having ten threads to the inch. This nut is in two parts, and can be tightened up by screws, so as to prevent any lateral play; and a collar and washer, also adjustable, prevent any play in the headstock. The other end of the bed has also a headstock and a screw movement, so as to adjust the length of the pieces in the groove, and to bring the readings of the index to 0. The difference between this machine and Mr. Whitworth's is in the way the subdivisions of the inch are obtained. In the Whitworth machine a screw, with exactly ten threads to the inch, is first made; whereas in this machine, as a screw could not be found with exactly ten threads, it was necessary to run a thread on the face of the hand wheel, and to subdivide this for the length required for an inch.

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[1] *Ibid.*, pages 39 and 57.

The manner of obtaining duplicates with such a machine is very simple. First, a piece of metal exactly one inch in length is cut, and from it a second piece is made in the machine, by means of the gravity piece; then pieces, 3, 4, 5, 6, of 2, &c., up to 100 inches are cut. These sizes are now kept as duplicates. The finer dimensions are read from the divisions on the wheel, and from these, gauges for the use of the workshop are now made. All dimensions are thus duplicate multiples, or divisions of an inch, and a bare one-sixteenth of an inch becomes not an unknown quantity, variable with the rule or the eye of the workman, but so many thousandths of an inch, which are stamped on the gauges, and are soon understood. One of the first applications of the system in the workshop was to establish the necessary degree of tension required to insure the perfect fit of a wheel on its axle. Two workmen were directed to make a pair of male and female 6-inch gauges for this purpose; the one allowed ·012 of an inch, the other ·003 of an inch, taking the larger dimension first, and gradually reducing the difference. The experiments gave the following results:

EXPERIMENTS on DIFFERENCES in DIAMETER in Boring and Turning WHEELS and AXLES.

No. of Experiment.	Length of Boss.	Diameter of Boss.	Diameter of Axle.	Difference in Diameter.	Permanent Stretch of Boss.	Remarks.
	Inches.	Inches.	Inches.	Inch.	Inch.	
1	7·0	5·988	6·000	0·012	0·006	Very tight. After pressing off, wheel and axle cut and slightly taper.
2	7·0	5·992	6·000	0·008	0·004	
3	7·0	5·995	6·000	0·005	0·002	
4	7·0	5·995	6·000	0·005	0·003	Very smoothly bored and turned.
5	7·0	5·997	6·000	0·003	0·000	Ditto; rather too easy a fit.
6	7·0	6·495	6·500	0·005	0·001	Axle slightly taper; diameter at 1·5 inch from outer end . . 6·498 inches.
7	7·0	6·493	6·500	0·007	0·003	Tight. Ditto „ „ 6·498 inches.
8	7·0	6·491	6·500	0·009	0·005	Very tight. Ditto „ „ 6·497 inches.

From this Table it will be seen, that with a difference of ·005 of an inch in the dimensions, there is a very small, permanent set in the wheel boss, but with a difference of ·003 of an inch the set is hardly perceptible. It was found, however, that with ordinary lathe work, ·003 was rather too fine a dimension, as lathes are seldom exactly true in their spindles, some boring slightly taper, and some an oval hole. The size ·005 was finally adopted, and for some years past all the wheels and axles have been adjusted to those dimensions.

In shrinking on outside cranks it was found, by a series of experiments similar to the above, that a difference of ·015 of an inch was amply sufficient to retain them in their places, the old allowance being ·030 of an inch; while crosshead spindles, of 2½ inches diameter, pushed into their places by hydraulic pressure, require a difference of ·004 of an inch; and levers with 3-inch holes require a difference of only ·001 of an inch, when they have to be driven into their places with a lead hammer. All these dimensions were previously empirical; but with this system of working they become known quantities.

The gauges used are exceedingly simple. Each consists of a piece of steel about 1 inch wide, parallel in the width, two-eighths of an inch thick in the middle, and tapered towards the ends, which are rounded. Each gauge is made nearly to the required length. The ends are then hardened, and the bar is brought to the correct standard by a whetstone. This gauge should just pass through the eye of a wheel. The gauge for the shaft is of the horse-shoe shape, and is made of steel, with the ends hardened. For wheel work, the lathe men have copies of these gauges, and the foreman of the press-shop has also copies, and it is his business to try if the wheels and the axles are turned to the gauges, and if they are not correct, to reject them. It will be seen from this, how accuracy is not only easy of attainment, but how it is checked. There is no difficulty in this way of working; it has been in use for years, and a misfit is unknown. The valve motions of locomotive engines having to sustain a great deal of wear, from the speed and pressure on the backs of the valves, the pins and joints require to be carefully fitted and case-hardened, after which they are ground to fit their places. While exposed to the carbonizing process, the pins expand and the joint-holes contract. With the measuring-machine, this expansion and contraction is easily found, and an allowance being made for it in the boring and turning, only the smallest amount of "lapping" out is required, and a great deal of grinding is saved.

Plate 22, Figs. 9, show how the lengths of the eccentric rods are preserved uniform. A is a hollow casting, supported on legs, and being about the same height as a workman's bench. This casting is planed on three sides, and two castings, D D, which are facsimiles of the eccentrics, are bolted on at one end. At the other end two jaw-pieces E E are bolted on, corresponding to the position which the links bear to the eccentrics. The workman first scrapes the eccentric straps to D, and the joint is then brought down over the jaws E E, and the pin F must pass through the joint and the jaw-piece. The rod is now perfect as regards length, nor can there be any twist in the joint or pin, and the strap and rod are now ready for hanging on the engine from the hands of the fitter. Plate 22, Figs. 10, show how the key groove is cut in the outside cranks. A strong casting A, has its top and bottom surfaces and the top of the lugs B planed; a wrought-iron plate C is then fastened to the lugs B, and the tool being taken to the lathe, the holes D and E are bored in it. The key bed and hollowed-out part in C are carefully set out, and after being cut, the plate is case-hardened, and a large pin F is turned to fit the holes. The crank H is pushed through between the surfaces A and C, until the crank-pin fits the hollow part in C. The pin F is then pushed into its place, and the set screws being brought down on the crank, the work is ready for slotting. The eccentric key grooves are cut in a precisely similar way; no setting out is required, and there is no chance of any mistake from the carelessness of the workmen. The cranks and eccentrics must be exact, or they will not fit these tools, and thus a certainty is attained in the depth and the position of the key groove. The corresponding templates for cutting the grooves in the axles are shown in Plate 22, Fig. 8.

Considerable improvements have been effected in plate-moulding during the last few years, and no system of machine-making would be perfect, without their application in the foundry. The plan adopted at the Midland Railway works at Derby is not new, but it is believed to be its first application to such large and complicated castings as locomotive cylinders.[1] Plate 22, Figs. 11 to 17, show how the cylinders are moulded. Fig. 11 shows one-half of one of the patterns ready for moulding. A is a hollow-plate casting, the surface of which is planed for the half pattern to lie upon; eight small strips on the edge of this plate are also planed, to fit a large template, which has four holes in it corresponding to the pins D D. The moulding boxes have corresponding strips on all their edges, and after their joints are planed, these strips are planed to fit the same template; all the pin holes for the plates and the moulding boxes being drilled with a pin drill from the template. Centre lines are also run on the boxes and the plates from centre lines on the template, and the half patterns are then attached to the plates by pins, the centre lines on the patterns corresponding to the centre lines on the plates. Fig. 12 shows how the steam chest is moulded. A is a planed surface plate as before, and a pattern, representing the surface of the steam chest, is inserted in it at M, as shown in plan, Fig. 13, and two elevations, Figs. 12 and 14. The moulding box is dropped on the pins D D, and the sand is rammed up as usual, after which the box is ready for the drying stove. Figs. 15, 16, and 17, are longitudinal and transverse sections of the moulding boxes, fixed together ready for casting.

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[1] Moulding boxes for axle brasses were exhibited at the Meeting.

The core barrel G has strong castings at each end I I I I, which are bored for the spindle K H K, and are turned on the outer edge to fit the moulding boxes. The middle part of the core barrel is a wrought-iron plate, pierced with holes, on the outside of which is shown the hay-band and the core. The four different box parts are shown at C 1, C 2, C 3, and C 4. Box C 1 is moulded from a plate as shown in Fig. 12. Boxes C 2 and C 3 are moulded from half patterns as in Fig. 11. These two boxes C 2 and C 3 have their ends carefully bored out from the centre lines to fit the turned parts of the core barrel, so that the weight of the core is not sustained by the sand, but rests on the metal of the box part. C 4 is moulded on a plate similar to Fig. 12, and requires no especial description. The steam and exhaust cores are moulded in cast-iron core boxes, carefully fitted on the inside, and the cores are placed in the stove in their own boxes, and by that means are free from twist, and are accurate in length and shape. As will be seen from the sections, a minimum quantity of sand is used, and the projecting pieces cast on the boxes do away with all lifters. By this mode of moulding, the castings come cleaner from the sand, the patterns are not knocked to pieces by rapping, the cylinders are perfectly true in the bore and passages, and at the same time the manufacture is brought within the grasp of any man who can throw in the sand and ram it. Fig. 16 shows partly an end elevation, and partly a section, of the boxes fitted together; the holes O O O being for pouring in the metal and for the rising head.

It would be tedious to describe the different templates and gauges used in completing the various parts of a locomotive engine made on this system. It will be sufficient to say, that each separate part is as carefully fitted as those already described, and that all the dimensions are obtained from duplicate templates, representing inches and parts of an inch, to three places of decimals.

Plate 23, Figs. 1 and 2, show the first step in fitting together the various pieces, so as to insure uniformity in erection as well as in construction. A is a large surface plate, strengthened by deep ribs and bars, the surface and edges being planed. Two brackets B B are bolted to this plate, and have all their faces and edges planed. The cylinders, after being fitted together, are placed on the two brackets, the parts on which they rest being also planed. The two brackets C C have recesses planed in them to receive the slide bars, and it is the duty of one set of men to fit the slide bars D D, the spectacle plates, the cross head and slide blocks, the piston and rod, the valve spindles, guides, and pumps. When all these have been fitted together, the next operation is to lift them on to the cradle C C, Plate 23, Figs. 4 and 5, which show the mode of erecting engines from a true plane, all the upright lines being squared up from the beams A A, B B, the horizontal lines being obtained by a surface gauge working on the same true surfaces. The cradle C C is firmly fixed on the two cast-iron girders A A, about 30 feet long. Their upper surfaces, which are slightly above the floor of the workshop, are carefully planed, as well as the edges and the grooves which correspond to the edges of the rails. The planed lower edges of the cylinders, already described, rest on the planed surfaces of the cradle at the proper angle, and are brought to the centre lines on the cradle F F, by the set screws at E E. At the ends they are adjusted to lines which pass through the cylinders to the uprights S S, the longitudinal position being obtained by a straight edge laid on the face of the cylinders, corresponding with the planed surface on the front of the cradle, on which are drawn the centre lines. The inside frames L L are then attached to the cylinder; the holes of both being drilled to a template, only require rose-bitting, the end of the frame being supported by the upright at N. The outside frames J J are then attached, by means of the bracket plates and the buffer beams. As the pieces R R R correspond to the position and dimensions of the axle-boxes, all that is required is to describe on the horn blocks lines squared up from these pieces. These are then removed, and being planed to the lines, the boxes are fitted into their places; after which the wheels, motions, and rods, being hung on, the engine is run over another pit to have its boiler put on, an operation which does not require a special description.

It will be seen, from this description, how parts, however large, may, by this system of accurate measurement, become duplicates of one another, and can at any time be replaced; and that the parts become interchangeable, so that any part may be sent to a distant station, with the certainty of fitting when it arrives there. The advantages claimed are, first, economy in manufacture; secondly, greater perfection in workmanship; and thirdly, an accurate system of duplicates, whereby the parts become interchangeable. The Author especially recommends this system to the Engineers of Indian and Colonial Railways, and he sees no reason why the different parts of the engines and rolling stock sent to those places should not be as perfect duplicates, as the different parts of the Enfield rifle.

The communication is illustrated by a series of diagrams, from which Plates 22 and 23 have been compiled.

Mr. Fernie stated that the whole system was founded on the application of Mr. Whitworth's true plane. He explained the mode of working with the different machines and tools, of which several specimens were exhibited, including the gauges, which could be regulated to the 1000th part of an inch, the moulding boxes, and the callipers used for taking the diameter of wheels.

Mr. Bramwell said, that while there could be no question as to the great advantage to be derived from the use of such delicate and accurate means of measurement as those alluded to in the Paper, nevertheless there were many factories which did not possess, and perhaps for a long time to come would not possess, such expensive measuring implements. This being so, he thought it might even now be of service to allude to a plan that he had used for insuring the accurate boring of tires, which, looking at the small range there was between a loose tire on the one hand and a burst tire on the other, was a matter that demanded the greatest care. The plan was this; to make a gauge so much shorter than the correct bore of the tire, that when the gauge was put inside the tire and one end of it was kept stationary, the other end could be vibrated some convenient measurement, say $\frac{1}{50}$ part of the diameter of the bore. If, for example, the tire were to be bored out to 50 inches diameter, then the gauge would be made so much less than 50 inches in length that its moving end could be vibrated exactly 1 inch. Then assuming that such a gauge were applied to a tire in which it could only vibrate $\frac{9}{10}$ of an inch, it would indicate that that tire was bored $\frac{1}{100}$ part of this difference too small, or, in other words, it would detect an inaccuracy in bore of $\frac{1}{1000}$ of an inch; and as a workman could, with the greatest readiness and certainty, read a measurement much finer than $\frac{1}{10}$ of an inch, say four or five times as minute, it followed that he would, by this contrivance, be enabled to detect errors in bore as small as even $\frac{1}{4000}$ or $\frac{1}{5000}$ of an inch. There was also this convenience in the use of such a mode of measurement, that the gauge could be got within the tire before the full bore had been attained, and in this way the finishing cuts could be watched and regulated with the greatest nicety. Looking at this, by no means inconsiderable, advantage in working, and at the great delicacy of measurement obtained by such simple and inexpensive implements, Mr. Bramwell believed that this plan, of making the gauge so much smaller than the true bore of the tire as to admit of a definite vibration within that bore, was far better than the ordinary mode of having the gauge the full and exact length of the intended internal diameter.

Mr. Beyer remarked that great credit was due to the Author for the trouble he had taken in getting up the illustrations for his Paper; but the substance of the communication was rather more

Fig 12.

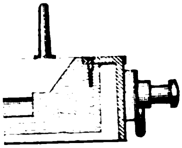

Fig: 11.

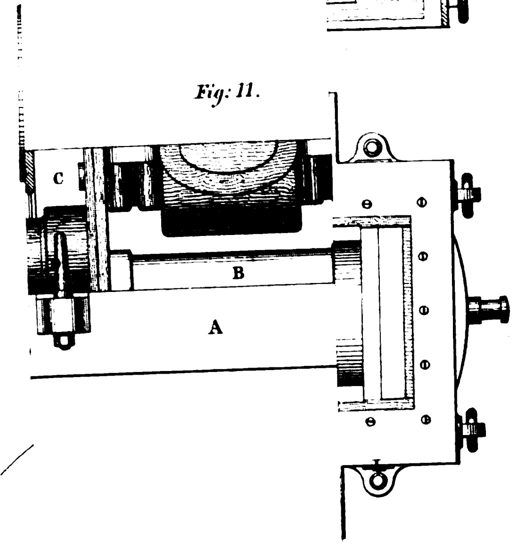

Fig: 14.

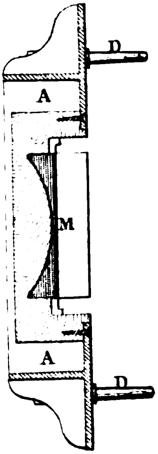

Fig: 15.

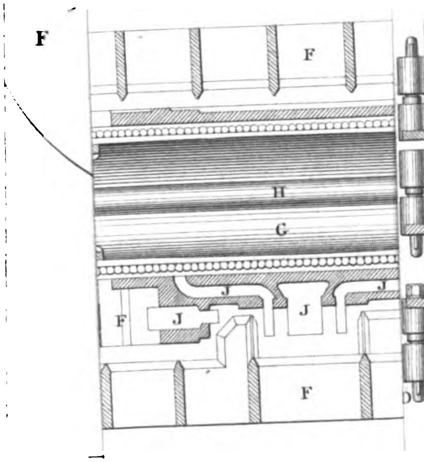
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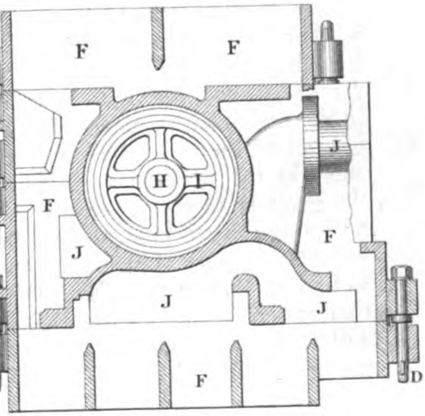
Fig: 17.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13. 14.

KELL BROS LITH. CASTLE ST HOLBORN.

suitable for a school of Engineering than for the Institution. The subject was an old one. Mr. Richard Roberts had supplied duplicate machinery thirty years ago, and for more than twenty years Mr. Beyer had been engaged in making duplicate locomotive engines, and had made such for the greater number of the railways in this country, including the Midland Railway.

Mr. VIGNOLES stated, that Mr. Beyer had manufactured upwards of fifty locomotive engines for the Tudela and Bilbao Railway, which were exact duplicates of each other, and of which all the parts perfectly fitted on their arrival in Spain. He was glad to have this opportunity of expressing his fullest confidence of the way in which the duplicate system had been carried out, and he too was surprised, that it was not more generally known and adopted.

Mr. FERNIE conceded that all honour was due to Mr. Beyer, for the excellent manner in which his work was executed. He quite understood that mode of working, but something more was required, and it should be stated, in justice to the large firms who devoted themselves to railway work, that all of them had for years been aiming at a system of duplicates. The plan now laid before the meeting was, however, different from the others, inasmuch as it was a system of working from known gauges. It was not the custom of railway companies to order all their engines from one maker. Twenty might be purchased from one firm, thirty from another, and so on, and on some lines there were as many as twenty different types of engines. Now, by the system of Mr. Whitworth, all the engines from those various manufacturers would be perfectly alike, whereas, by what might be termed the individual system, only the different lots would be duplicates of one another. There was no doubt that, at the present time, there was a want of uniformity in the dimensions of engines, as supplied by different makers, and what was wanted was, a standard by which all makers should work alike. The parliamentary yard of 36 inches must be the standard, and from the inch, as he had already shown, it was an easy matter to obtain any dimension. He had said that the engines were, as a rule, unlike in their dimensions; but a slight correction was required in this statement, for all the screws were of the same pitch and thread, and every nut would fit every bolt of its own diameter. It was hardly possible to calculate the immense saving to the country through the adoption of Mr. Whitworth's taps and dies; and yet when they were first introduced, they were not generally approved, and one firm in Manchester hesitated for many years, until at last they were compelled to adopt them. No one, he thought, would now raise an argument against them, for their many advantages had been realized; and so with regard to this new system, he expected there would be some opposition to it. This was an age of precision, and from a careful working for five years on this system, he was satisfied of its practicability, and thought that hereafter it would be carried out with still greater minuteness. He felt certain the time was not far distant, when there would be no more guesswork as to the finer divisions of the inch. It was only necessary to show mechanical men the importance of accuracy of dimensions, and the ease by which that accuracy could be attained, and their own good sense, and desire to excel, would soon prompt them to adopt the new system. This was quite as much a question for the manufacturer as for a railway company. If England was to continue to be the manufactory of the world, let the makers take up this system, and with excellence of material and scientific precision of construction, so attain to the perfection of production.

In pursuance of the notice on the card of the meetings, it was proposed, and resolved unanimously:—"That in order to avoid holding a Meeting on the evening of Whit-Tuesday, the meeting be adjourned until the evening of the 2nd of June."

June 2, 1863.

The Session was concluded by a Conversazione, at which the President received the Members of the Institution, and a numerous circle of distinguished visitors. The rooms were decorated with many choice works of art, and there was also exhibited a large and interesting collection of mechanical models.

APPENDIX TO VOL. XXII.

MEMOIRS.

HIS ROYAL HIGHNESS ALBERT FRANCIS AUGUSTUS CHARLES EMMANUEL, DUKE OF SAXE COBOURG AND GOTHA, PRINCE CONSORT, K.G., K.T., K.P., G.C.B., K.S.I., G.C.M.G., &c., &c., was born August 26, 1819. He joined the Institution of Civil Engineers as an Honorary Member on the 7th of March, 1843. H.R.H. died December 14, 1861.

MR. PETER BARLOW was born in Norwich, in October, 1776, and was sent at an early age to a foundation school, where he acquired a good English education. He was then placed in a mercantile establishment in Norwich, and while in that position and still at an early age, he, together with some young friends of a similar turn of mind, formed a juvenile scientific society, where they discussed questions in mathematics and the physical sciences, for which young Barlow had a natural predilection, and eventually by his industry and perseverance he acquired considerable scientific knowledge.

The political excitement of the times broke up this little society, and the members of it became dispersed, some entering the Army and others the Navy, whilst Mr. Barlow, turning his attention to tuition, for which he had partially qualified himself by careful study, although without enjoying the advantage of good masters, obtained the mastership of a school. He soon became a regular correspondent of 'The Ladies' Diary,' then under the management of Dr. Hutton, Professor of Mathematics at Woolwich, under whose advice Mr. Barlow was induced, in 1801, to become a candidate for the post of additional Mathematical Master at the Royal Military Academy, a position which was only obtained after a severe competitive examination. There he became acquainted with Mr. Bonnycastle, to whose judicious advice and assistance he always acknowledged himself to have been much indebted. Under the same advice he, in 1808, commenced writing for the 'Encyclopædia' conducted by Dr. Rees, and from the letter H to the end, he contributed the majority of the mathematical articles of that work. In 1811 he published his first work on the 'Theory of Numbers,' and in 1814 appeared his 'Mathematical Dictionary,' and immediately afterwards his 'Mathematical Tables,' a work which has since been reproduced by the Society for the Diffusion of Useful Knowledge. In 1817 he published the first edition of an 'Essay on the strength of Timber and other Materials,' founded on experiments made in the Dockyard and the Arsenal at Woolwich, by permission of the Admiralty and of the Board of Ordnance. While thus engaged he became acquainted with the late Thomas Telford, and assisted him in experiments and calculations for his then proposed structure of the Menai Suspension Bridge, and also conducted for him a series of experiments on the tides in the Thames, in reference to the then projected erection of the new London Bridge. In the report upon the latter subject, the effects which the removal of the old London Bridge have since manifested upon the bridges of Westminster and Blackfriars were fully considered. About this time he also contributed many articles to the 'Encyclopædia Metropolitana.' In 1819 his attention was directed to the variation of the compass needle and the local attraction of ships, and he was induced to undertake a series of experiments, with a view to discover the laws of the reciprocal action subsisting between magnets and simple iron bodies, and to devise some means of correcting the errors of compasses on shipboard. The Government liberally allowed him the facilities which the Dockyard and Arsenal at Woolwich presented for prosecuting these experiments, and the laws of terrestrial magnetism which he, after much labour, discovered were subsequently confirmed by Captain Basil Hall, Captain Mudge, and other officers. These laws and their proposed application for correcting the local attractions of ships formed the subject of his 'Essay on Magnetic Attractions,' published in 1820. In a second edition of this work, in 1823, it was shown that all the laws which had, up to that time, rested on experimental deductions were consistent with a certain hypothesis of magnetic action, which theory was subsequently elaborated and confirmed in a more general investigation of the subject by M. Poisson, in a memoir read to the Institute of France in 1824. All doubt on the subject being now removed, Mr. Barlow received numerous gratifying marks of approbation. He was elected on the Council of the Royal Society, and received the Copley medal. He also received the reward for useful discoveries, provided by Parliament, in connexion with the then existing Board of Longitude. He further received a handsome personal present from the Emperor of Russia, and was elected a member of the Imperial Academy of Brussels, a corresponding member of the Institute of France, and received many other similar distinctions.

On the 31st of January, 1825, he presented to the Institution of

Civil Engineers a communication 'On the Force exerted by Hydraulic Pressure in a Bramah Press; the resisting power of the cylinder, and rules for computing the thickness of metal for presses of various powers and dimensions.'[1]

Mr. Barlow next turned his attention to electro-magnetism, and was the author of a work on that subject. While engaged in the experiments he conceived the idea of making electric signals by deflecting a magnetic needle with a current of electricity, generated by a galvanic battery, and passed along a conducting wire. With this object he caused an experiment to be made upon a mile of copper wire, arranged upon posts in his garden, at Rushgrove Cottage, Woolwich. The battery employed consisted of about twenty pairs of plates 15 inches square. No insulation was given to the wires, and no coil was employed to multiply the action upon the needle. In this experiment, which contained the germ of an invention destined afterwards to become of such important public utility, although a certain amount of deflection was obtained, yet from imperfect insulation increased length of wire was found to produce great loss of power, and as other subjects of great interest occupied his mind at this time, he discontinued his experiments upon the electric telegraph.

Although engaged at this time in contributing articles to several scientific works, he applied himself to the improvement of achromatic object-glasses, on which subject he communicated a paper to the Royal Society.[2] Pursuing this subject, he was led to try the effect of substituting a fluid contained between two sheets of plate, or crown glass, instead of using the concave flint glass lens, generally employed, and he constructed two telescopes on this principle. Subsequently the Council of the Royal Society engaged Mr. Dolland to construct a fluid lens telescope under his superintendence, the result of which was satisfactorily reported upon by Sir J. Herschel, Professor Airy, and Admiral Smyth.

Between the years 1833 and 1835 he was engaged in the prosecution of an extensive series of mechanical and other experiments, and in the production of a volume containing a description of 'The Manufactures and Machinery of Great Britain.'

The railway system was at this time in its infancy, and before Engineers had established practical data, Mr. Barlow was much occupied in experiments, and in testing the strength and best form of section of railway bars, the effect of gradients and curves, and in determining other questions.

In 1836 he was appointed one of the Royal Commissioners for determining the best system of railways for Ireland, the report on this subject being presented to Parliament in 1838.

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[1] *Vide* Trans. Inst. C. E., vol i. p. 133.

[2] *Vide* Phil. Trans., 1827, p. 231.

In 1839 he was appointed on a similar commission for determining the best route to Scotland and Wales, and the most convenient port for steam communication with Ireland.

On the 5th of March, 1839, a Paper of his was read at the Institution of Civil Engineers, intituled 'An Investigation into the Power of Locomotive Engines, and the effect produced by that power at different Velocities.'[1]

In 1842 he was similarly employed upon an inquiry into the general merits of the atmospheric system, and in 1845 he was appointed one of the Gauge Commissioners, in which he was associated with Sir Frederick Smith and Professor Airy.

In 1847, being then seventy-one years of age, he retired from his duties at the Royal Military Academy, and in consideration of his eminent public services, the Government awarded him his full pay on his retirement.

From this time, although he ceased to engage in active professional duties, he continued to take a lively interest in all the leading scientific questions of the day.

So late as the year 1857, although he was eighty-one years of age, he wrote a postscript to a Paper communicated to the Royal Society by his son, Mr. W. H. Barlow, M. Inst. C. E., on the 'Resistance of Flexure,' which postscript contained a mathematical investigation of considerable difficulty.

Mr. Barlow was elected a Fellow of the Royal Society in May, 1823, and he was a member of most of the other scientific societies of this and other countries. He joined the Institution of Civil Engineers as an Honorary Member in 1820, and always took much interest in the proceedings. Of a kindly and cheerful disposition, he retained his full powers of mind until his death, which took place on the 1st of March, 1862, deeply regretted by his numerous friends, and especially by those Officers, his former pupils, who, whilst under his guidance at the Royal Military Academy, had ever found him as valued a friend as a conscientious and talented tutor.

MR. JAMES JOHN BERKLEY was born at Holloway, on the 21st of October, 1819, and completed his education at King's College, London, under Dr. Major. He was articled to Mr. Wicksteed (M. Inst. C. E.), then Engineer of the East London Water Works, in the year 1836; but very soon left him, and entered the office of Mr. G. P. Bidder (M. Inst. C. E.), and in 1839 he may be said to have commenced his real pupilage under Mr. Robert Stephenson (M. Inst. C. E.), by whom he was very actively employed, travelling with his chief, writing reports for him upon his numerous works, arbitrations, and other engagements.

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[1] *Vide* Minutes of Proceedings, Inst. C. E., vol. i. (1839) p. 46, and Trans. Inst. C. E., vol. iii. p. 183.

Among these may be mentioned the Bute Docks at Cardiff; the examination of a system of railways projected to connect London, Brussels, and the various towns of the north of France, with Paris, which was reported on by the late Robert Stephenson in 1842; the Hesse Cassel and the Leopold Railways; the construction of the Northampton and Peterborough, the Trent Valley, the Churnet Valley, and the North Staffordshire Railways, on which latter Mr. J. J. Berkley held the position of Resident Engineer.

At the latter end of the year 1849, an Engineer of ability, experience, and judgment being required to go to Bombay to lay out an extensive system of railways in that presidency, Mr. J. J. Berkley was so strongly recommended for the important work by the late Mr. Robert Stephenson, Mr. Brunel, Sir W. Cubitt, Sir John Rennie, Mr. Bidder, and other eminent Engineers who knew and appreciated his talents, that he was unhesitatingly appointed to the position of Chief Resident Engineer of the Great Indian Peninsula Railway, and he left England for India in January, 1850.

The Company's undertaking was at that time confined to the construction of 33 miles of "experimental line" from Bombay to Callian, and having early decided the most important points connected with the course of that line, through the town of Bombay, and the mode of crossing the creek which divided the island of Bombay from the mainland, Mr. Berkley turned his attention to the extensions which he perceived would inevitably be called for, and to the means of surmounting the great barrier of the Western Ghâts, which any extension into the interior immediately involved. The original projectors of the Great Indian Peninsula Railway proposed to make one ascent of the Ghâts, bifurcating at the top to the north-east and the south-east; but an examination of the line of Ghâts led Mr. Berkley to report unfavourably of that scheme, on account of the almost impracticable nature of the works, and to recommend the adoption of lines branching off from Callian to the south-east and north-east, ascending the Ghâts at the Bhore Ghât and the Thul Ghât on the line of a large existing traffic.

In 1852 the surveys for both the lines were commenced. Four years were spent in the surveys of the Bhore Ghât, and during that period Mr. Berkley laboriously worked out the details of the plans and designs.

On the 16th of April, 1853, the first 20 miles of the line, from Bombay to Tanna, were opened for public traffic, thus initiating the Indian railway system. This is alluded to in a very interesting letter from Sir Bartle Frere, who, doing full justice to the intelligence, skill, and energy of Mr. Berkley, alludes to the previous unexecuted scheme of Mr. George Clark, in 1844, which, he says, preceded the plans of Mr. Chapman, and of Sir Macdonald Stephenson, to whom, however, he gives credit for their energy and perseverance, and in pressing forward their plans to fruition.

Considerable delay occurred in obtaining official sanction to the Thul Ghât portion of the scheme, owing to the Government of India having entertained a project for turning the Ghâts, by a line from Surat along the course of the Taptee River. This resulted in further surveys and elaborate reports on the Ghât ascent, by which the superiority of the line, as proposed by Mr. Berkley, was fully established.

In 1856 the North Eastern Line, viâ the Thul Ghât, was sanctioned by the Government of India, thus completing the Great Indian Peninsula system of lines, as projected by Mr. Berkley, comprising a total length of 1,237 miles, forming a grand trunk communication, by the North Eastern line, between Bombay, Calcutta, and the North-West, and by the South Eastern line, between Bombay and Madras; including also an important line to Nagpore, passing through some of the most extensive cotton districts of Western India.

The control which the Government exercises, under the guarantee system, has unquestionably been a source of special difficulty to the Engineers of the respective companies, and it was mainly due to Mr. Berkley's firmness and tact that a minute and harassing supervision was avoided, and that efficient co-operation established between the company and the Government authorities, which has generally subsisted on the Great Indian Peninsula Railway, to the manifest advantage of both parties.

Mr. Berkley was a firm and zealous advocate of the contract system, under which the whole of his works were constructed. The system on a large scale was new in India and was regarded at first, by the Government, with some suspicion; it has now, however, been adopted almost entirely in the public works, with the best effect in the rapidity and extent of their operations.

The details of the great works, comprising the inclines of the Ghâts, are so well known, from the description given by Mr. Berkley in his address to the Mechanics' Institution at Bombay, and from other publications, that it is only necessary here to allude to the satisfactory solution of the question of practicability, by the successful working of them with enormous traffic, although these inclines exceed in difficulty and importance those of the Sömmering, and the Giovi. In connection with this undertaking mention should be made of the courage of the widow of Mr. Solomon Tredwell, the Contractor, who, after his too early decease, determined, for the honour of her husband's name, to continue the works, and with the efficient aid of Mr. Clowser and Mr. Adamson, did complete them most satisfactorily.

The labour entailed upon Mr. Berkley by the works he had undertaken, affected his health, and he visited England in the year 1856. Advantage was taken of the opportunity, by a number of the principal Civil Engineers, to invite him to dine with them; when Mr. Robert Stephenson, who occupied the chair, spoke thus of his former pupil:—

"Gentlemen,—I have very sincere pleasure in presiding at this entertainment, which is offered to my friend Mr. James Berkley. I feel that on the present occasion it is not necessary to enlarge upon the professional acquirements, or talents, or the social virtues of my friend, for he has already prominently brought himself to your notice by his professional abilities under exceedingly trying and adverse circumstances, and by the esteem in which he is held by all who know him. Very early in his life, and when I was tolerably advanced in my career, he was introduced to my notice as a young and professionally inexperienced man, but a very short acquaintance and association with him, convinced me that he was possessed of a good heart and a good head, and in a short time he became not only confidentially associated with me in professional life, but my intimate friend in my domestic circle. I freely imparted to him my own views and opinions, and employed him in the construction of several of the principal lines intrusted to me. When the opportunity for his going to India presented itself, I felt that he had embarked in an exceedingly difficult task. Having myself been thrown in early life upon my own resources, in a foreign country, where engineering operations were of a very difficult character, I well knew the variety and nature of the obstacles he would have to encounter, and you will readily comprehend how operations, even such as are easy in this country, would become extremely arduous when undertaken abroad. The Directors of the Railway Company were influenced by my recommendation, strengthened as it was by the highest testimonials, and my friend went to India, where he has amply justified the opinion I had formed of his capabilities, and has successfully overcome numerous difficulties and impediments of no ordinary character. A favourite expression of my father's, in his early career, was—'I can engineer matter very well, but my great difficulty is in engineering men.' Mr. Berkley has, I am happy to say, succeeded not only in engineering matter in a foreign country, with few available resources for railway operations, but he has also been eminently successful in that more difficult task of engineering men. No small tribute to his talents and temper.

"It is scarcely necessary for me to do more than allude briefly to the works executed by our guest, during his comparatively short stay in India. He has already executed 90 miles of railway which are on the point of being opened, as far as the Ghâts, the great physical feature of the West of India. The question of the ascent of the Ghâts, is one of considerable difficulty, and demanding much knowledge, skill, and consideration. Excellent designs of them have, however, been prepared by Mr. Berkley, and the explanations he has afforded me are so minute and interesting, that I assure you I should feel proud of being the author of the plans he has proposed. Throughout these operations he has encountered all the formidable obstacles which the Ghâts present, and has overcome them with remarkable success. And this redounds all the more to his credit, when we consider, that the Ghâts present greater engineering difficulties than either the passage of the Sömmering to Trieste, or the Giovi Incline between Turin and Genoa; and that the ascent of those mountains was long considered barely practicable. Although those mountain inclines are serious undertakings, it is compulsory for the good of the country to make and to maintain them, and, in spite of all difficulties, Mr. Berkley has, after six years of laborious research, succeeded in designing a series of lines, which I have no doubt will be amongst the most successful in the world. I trust, however, that greater wisdom will be displayed by the Indian Government than by our home legislature in that respect. That they will be watched over with something more like parental care, for here they have been deserted like prodigal sons. India demands accommodation for an enormous traffic and population, and if the railways are permitted to be extended with discretion and wisdom, there cannot be a question that they will be both beneficial to those who have invested capital in the enterprise, and of incalculable advantage to that important country. My friend at my side has also the honour, whether accidental or not, of being the engineer who constructed and opened the first railway in India. This is no small credit to him, and in all that he has done I feel proud of him, and that he has reflected honour upon my recommendation."

Notwithstanding the extent and the laborious nature of his professional duties, Mr. Berkley took an active part in many of the useful and scientific institutions of Bombay. In the Mechanics' Institution especially he took a lively interest, and by his personal exertions and active measures, as President, he greatly increased its sphere of public utility, and gave an interest to its proceedings which had before been wanting.

The Council of the Mechanics' Institution has accorded a "Berkley Gold Medal" as an annual prize for competition among its members in commemoration of his valuable services, and the first gold medal was sent to his widow with a resolution expressing sympathy and condolence.

Constant demands were made upon his services, but he was obliged to decline everything except the nomination to such position as indirectly bore upon the chief events of his life. In 1855 he became a magistrate. In 1857 he was appointed one of the commissioners of the Municipal Board, and in 1858 he was elected a member of the Senate of the Bombay University.

Mr. Berkley's energy of mind far exceeded his physical strength, which was suffering severely from the effects of the Indian climate, so that in April, 1861, the state of his health compelled him to return to England. At that time he had the satisfaction of seeing his plans and designs of the Bhore Ghât, his most cherished work, fully developed, and the works being carried on with extraordinary activity under a very efficient management. He eagerly desired to return to India to witness the accomplishment of the great work he had designed and almost carried out to completion, but it was otherwise ordered; and after a lingering illness he closed his short but useful career, at Sydenham, on the 25th August, 1862.

From early boyhood, James John Berkley showed signs of great activity of mind and love of knowledge. He was a great reader, and was ever ready with his pen as a contributor to general literature, or as a clear and able writer on professional subjects. In after years, when his position in India called forth the particular talent, he proved himself both as President of the Bombay Mechanics' Institution, at the meetings, and on public occasions, a fluent and indeed an eloquent speaker.

By his devoted attention to the important duties of his office as Chief Engineer, in Bombay, of the Great Indian Peninsula Railway, by his high sense of honour, by his gentlemanly bearing and liberal sentiments, as well as by the kindness and consideration which he ever displayed towards all those who were connected with him in business, he deservedly obtained the esteem and affectionate regard of all who knew him.

The high estimation in which he was held is proved by the following extracts, which have been selected from numerous voluntary testimonials.

The Directors of the Great Indian Peninsula Railway in reporting his death to the shareholders stated :—

"The Directors have the melancholy duty of announcing to the Proprietors the death, on the 25th August last, of Mr. James J. Berkley, M. Inst. C. E., the Company's Chief Resident Engineer in India. Mr. Berkley from the commencement of operations in January, 1850, down to the beginning of last year, when his failing health compelled his return to England, conducted the whole of the engineering operations with remarkable devotion, energy, and engineering skill, to the entire satisfaction of the Directors. In order to record more permanently their sense of the valuable services which Mr. Berkley rendered to the Company, the Board have directed a tablet to be erected to his memory in some favourably conspicuous position at the Bhore Ghât Incline."

Sir James Outram, whose large experience of Englishmen in India, rendered him no mean judge of his fellow-countrymen, and who has established a world-wide character for truthfulness and talent, wrote to him on his leaving Bombay in 1857 :—

" MY DEAR BERKLEY, *Parell, 9th July,* 1857.

" I am loth to leave Bombay without seeing and bidding you good-bye, for which purpose I called at your old house in Mazagon, which I found shut up, and there was no one at the premises to tell me where you are. I am informed, however, that you are travelling in Candeish, I hope out of harm's way in these troublesome times.

"When your line meets our line (from Calcutta) I trust we may have personal communication, if not before ; but in the meantime I hope you will not scruple to command me, wherever I may be, for there is no one for whom I have a greater esteem, or to whom this Presidency is more indebted, than yourself.

" Believe me to be, my dear Berkley,
" Very sincerely yours,
(Signed) " J. OUTRAM."

In addition to the above, the Engineers on the staff of the

Great Indian Peninsula Railway, and a few other gentlemen in Bombay, united soon after the death of Mr. Berkley to prove their high appreciation of his talent, as well as their great esteem and affection for their late friend and companion, by a substantial testimonial.

In a few days a sum of nearly £3,000 was raised, and it was determined to erect a monument over the grave of their late friend, at a considerable cost, and to expend the remainder of the fund, amounting to about £2,000, in the establishment of a fellowship, to be called the "Berkley" fellowship, at the Bombay University. They well knew that the high value he attributed to education and the proper development of the powers of the mind, and the great interest he always evinced in this excellent university, would, were he living, render this, in his eyes, one of the most valuable testimonials of their regard which could be offered to him.

Mr. Berkley was elected a member of the Institution of Civil Engineers in the year 1855, and his Paper on "Indian Railways," in 1860, obtained for him a Telford Medal and a Council Premium of Books.

He was one of the men who, if his mission had not been to become one of the engineering pioneers in the East, would have risen to a very eminent position in the profession, for which he possessed the highest qualifications.

MR. JAMES COOPER was born at Highgate, in the year 1817. Soon after leaving school he entered the factory of Messrs. Cooper, of Old Street, where he only remained a short time, but where he acquired useful practical knowledge, which was of service to him in his future career.

After studying for some time under Mr. Hale, land surveyor at Colchester, he entered the office of Messrs. Walker and Burges, as a pupil, in the year 1835, and he rendered himself so useful that he subsequently continued with them as an Assistant, and finally was admitted into partnership with the firm in 1851.

Under the direction of, and in connection with, Messrs. Walker and Burges, he enjoyed rare opportunities of observing, and of being actively engaged in, many of the great engineering works of the period, such as the Caledonian Canal, the Middle Level Drainage, the Admiralty Works at Dover, Jersey, Alderney, Plymouth, &c., the Birmingham Canal, and the Lighthouses for the Corporation of the Trinity House, with many other important undertakings.

Whilst he was in charge of the works at the Edystone Lighthouse, in 1839, when it was decided to carry out Smeaton's intention of filling up the cavern in the rock, he nearly lost his life from one of those sudden risings of the waves to which the sea there is subject. The mason standing beside him was swept away, and was drowned, but Mr. Cooper continued his labours until the hazardous work was completed.

His decease was very unexpected, as there were not any symptoms which induced any anticipation of such an event. On Sunday, after church, he took a walk of only a few miles, and returned apparently without fatigue. After dinner his sisters quitted the dining-room, leaving Mr. Cooper and his father in conversation. On the servant going to the room to summon them to tea, both father and son appeared to be asleep; the former awoke, but the latter had in his slumber peacefully passed away. His death occurred on the 2nd of March, 1862.

The opportunities he enjoyed professionally were unusually good, and had his life been spared he might have taken a high position.

Mr. James Cooper was elected an Associate of the Institution of Civil Engineers in 1836, was transferred to the class of Graduates in 1838, and to that of Member in 1847. He was a very constant attendant at the Meetings, and frequently took part in the discussions.

MR. HENRY HINDE EDWARDS was born at Plymouth in November, 1800. His father, who was a practical Engineer and steam-engine builder, perceiving that there would be a good opening on the Continent, sent his son, in 1814, to complete his education in France, and he some time afterwards followed and settled in Paris, where he eventually became the partner of Monsieur Casimir Perier at Chaillot, and took his son into the works, of which, in 1829, Henry Hinde Edwards became the managing partner, as successor of his father, in the firm of Perier, Edwards, Chaper, and Co. The establishment, following closely after that of Messrs. Manby, Wilson, and Co. at Charenton, founded in 1820, became important in the history of mechanical engineering in France, and from thence there were produced large numbers of the double cylinder, high and low pressure engines, on Wolf's system, which are now so generally used on the Continent. Mr. Edwards also gave valuable aid in numerous establishments for mining, pumping water, grinding corn, &c., and displayed considerable mechanical ingenuity and skill. Among other works, he built, under the direction of Monsieur Polonceau, the cast-iron bridge across the Seine, called the Pont du Carrousel.

During the period of the political crisis, when all industrial undertakings were brought to a standstill, Mr. Edwards returned to England, whence he was eventually summoned to take charge of the Locomotive and Rolling Stock Department of the Eastern (Strasbourg) Railway, duties which he performed with undoubted skill and rare conscientiousness.

He joined the Institution of Civil Engineers, as a Member, in the month of December, 1855, but his residence abroad precluded his paying frequent visits during the Sessions. He was also a Member of the Société des Ingénieurs Civils de Paris, amongst whose members he, at his decease on the 13th February, 1861, at the age of sixty-one years, left many friends who sincerely regard his memory as that of a modest and honest man who had done good service in his particular sphere.

MR. JOHN EDWARD ERRINGTON, the eldest son of Mr. John Errington, a cadet of an old Northumberland family, was born at Hull, on the 29th December, 1806. He early evinced signs of great intelligence, and was remarked at school for his high spirit, for the prominent position he took in all his classes, and as being a general favourite with his masters.

Having shown in his youth great predilection for engineering and for the constructive arts, he was placed at an early age under an engineer officer, then conducting extensive public works in Ireland. After remaining some time on these works, he became the assistant of the late Mr. Padley in the various surveys which that gentleman conducted in the early stages of railways in this country. This employment brought him into connection with the late Mr. Rastrick (M. Inst. C.E.), by whom he was engaged to assist in various surveys, and his first active employment in railway projection was at the time of the preparation of the plans for the Birmingham end of the Grand Junction Railway, and it was at this period that Mr. Errington first met Mr. Joseph Locke, with whom he eventually became associated for the rest of his life. When the Grand Junction Railway came under the sole direction of Mr. Locke, he gave Mr. Errington an appointment as Resident Engineer, and intrusted to him the superintendence of the construction of a portion of the line, where he had an opportunity of making himself thoroughly acquainted with the practical methods adopted by Mr. Locke in carrying out the various contracts. After the completion of that railway, Mr. Errington took charge of the line from Glasgow, by Paisley, to Greenock, and the works were carried out under his superintendence: the harbour works at the latter port were also laid out by him, and the construction was carried on under his immediate supervision.

To an active and thoughtful mind like his it was not surprising that, during his residence in Scotland, various projects should have suggested themselves to him for connecting the political and commercial capitals of Scotland—Edinburgh and Glasgow—with England. At that time Mr. Vignoles had constructed the North Union Railway, a line extending from Newton, on the Liverpool and Manchester Railway, and virtually forming an extension of the Grand Junction line, to Preston, and various other projects were started to connect Preston with Lancaster. These lines would place Preston in direct communication with London, and the subject of extension northwards to Scotland had already occupied the attention of a Government Commission and of several of the most eminent Engineers of that day. The two principal projects, however, that interested the public in that special district were the rival schemes of Mr. George Stephenson for a coast line crossing Morecambe Bay and the direct scheme for uniting Lancaster and Carlisle by as straight a line as the nature of the country would permit. The plans for this latter project were deposited in 1842, under the name of the Caledonian Railway Company, with Mr. Locke as Engineer in chief. This project was, however, withdrawn; but it was brought forward again in a subsequent session, as the Lancaster and Carlisle Railway, and Mr. Errington's name was then associated with that of Mr. Locke as the joint Engineers. The immediate superintendence of the works remained in Mr. Errington's hands, and whilst Mr. Locke attended to various details of his largely-increasing practice in London, Mr. Errington devoted himself to the carrying out of the numerous bridges, viaducts, and other works which abound on that line.

Mr. Errington, although generally giving his assistance to Mr. Locke in the laying out of the several lines that came under Mr. Locke's charge, devoted himself principally to the works in the north of England and Scotland. He carried out the Caledonian Railway, upon which he evinced great judgment, by his mode of constructing the line across and forming junctions with the various tramways then in use for carrying on the traffic between the several collieries, without stopping the train. He constructed the Clydesdale Junction Railway, the Scottish Central, the Scottish Midland Junction, the Aberdeen Railway (now the Scottish North Eastern), and he either brought forward or was consulted about the entire system of railways from Lancaster to Inverness. After the commencement of the larger works in Scotland, Mr. Errington removed to London and devoted his attention to the various additions and branches made to the railways constructed under his and Mr. Locke's superintendence. About that period the London and South Western Railway Company were projecting anew their extension of the narrow-gauge system into Devonshire; and, owing to some difference between himself and the Board of Directors, Mr. Locke having ceased to be Engineer to that Company after the revival of their projects to the westward, the Directors naturally sought the advice and assistance of some well-known Engineer, whose antecedents might justify some knowledge of the locality. At this juncture they selected Mr. Errington, and under his direction various lines were deposited to meet the necessity which had arisen. After several deposits of plans and subsequent withdrawals, the Company finally sought powers to construct a line from Yeovil to Exeter. The plans for this project were deposited in November, 1855, and the Act received the royal assent in 1856. The works on the line were immediately commenced, and after great difficulties, owing to the heavy tunnels at Crewkerne and Honiton, the line was opened to the public in 1860. Several branches of this line were also constructed under his direction, and shortly after the completion of this work, Mr. Errington, whose health had been for some time precarious, suddenly became worse, and he expired at his residence in Pall Mall East, after a short illness, on the 4th of July, 1862, at the comparatively early age of fifty-five years, and he was interred at Kensal Green, in close proximity to his early friend and associate, Mr. Locke, who had not long preceded him to his final rest.

During the whole of Mr. Errington's career, both in Scotland and subsequently, when Engineer to the South Western Railway, he was actively engaged in various parliamentary contests, and the conscientious manner in which he gave his evidence, coupled with a marvellous power, which he had possessed from his childhood, of simplifying and bringing vividly before his hearers anything that he thought necessary they should know, gave his opinion great weight with the Committees before whom he was examined, and the Boards which he attended.

Mr. Errington, like his partner, Mr. Locke, had early learnt the lesson of endeavouring to make railways commercially successful, and his principle was therefore to study economy to the greatest possible extent; at the same time his taste in matters of art led him to combine elegance with strength and economy of design. His bridges on the Lancaster and Carlisle and the Caledonian Railways, those across the river Thames at Richmond, Kew, and Kingston, and lastly, the works of art on the Exeter line of the South Western Railway, show with what success his efforts were crowned.

In private life, Mr. Errington's kindness of heart, his great tact, and his affectionate disposition, tended to endear him to his associates and to his pupils. Possessed of sound talents and modesty, and a retentive memory, his society was sought by a large circle of friends, who deeply regretted his loss, and the respect of all his associates in his professional life was secured by his honourable character and fair dealing.

Mr. Errington joined the Institution of Civil Engineers, as an Associate, in the year 1831, and was transferred to the class of Members, on the 22nd of January, 1839. He became a Member of Council for the Session 1850, and was elected one of the Vice-Presidents for the Session 1861-62. He attended the meetings very regularly, took part in the discussions, was ever ready to advise and assist in every way for the benefit of the Society, and at his decease bequeathed the sum of One Thousand Pounds to the Institution.

He was a Member of whom the profession and the Institution might be justly proud, and his example should be carefully studied by the younger Members.

MR. JOSEPH LANE MANBY, the third son of the late Mr. Aaron Manby (M. Inst. C.E.), was born at Horseley, Staffordshire, December 22nd, 1814. At an early age he was sent to Paris for education at the school of Monsieur Massin, and in due time he was placed in the gas works of Manby, Wilson, and Co., where he studied gas engineering. He then returned to England, and was for a time engaged in the mercantile and banking establishment of Messrs. Jeremiah Harman and Co., Adam's Court, Broad Street, where he acquired the aptitude for commercial affairs which was subsequently so useful to him.

At the dissolution of the firm under whom he was engaged, he sought the advice of his father's old friend, Mr. George Lowe (M. Inst. C.E.), by whom he was induced to undertake the managewent in France of the concerns of the Continental Gas Company, which he continued to direct for some years. He then became connected with similar affairs in Spain, where he resided for some time, but he eventually settled in Paris, where, associated with the late Monsieur Savalète, he undertook contracts for the construction of the Seville and Cordova Railway, for some building speculations in Paris, and other works.

After the decease of his partner he came to London, in prosecution of some building speculations in Paris and elsewhere, and having some contract work in view at Cadiz, he, in 1862, visited that city. He there engaged to make a survey in Africa, where he received a sun-stroke, from the effects of which he rapidly sunk, and died shortly after his return to Cadiz, on the 18th of August, 1862, at the early age of forty-eight years.

Mr. J. L. Manby, although not strictly educated as an Engineer, had a very good knowledge of his special branch of the profession, and his natural talent and acuteness carried him through all difficulties. He was an excellent companion, a very well read and well-informed man, and possessed abilities which, under favourable circumstances, would have carried him probably to fame and fortune. He was deeply regretted by his relatives and friends.

He joined the Institution as an Associate in June, 1844, and was transferred to Membership in May, 1854.

MR. JAMES WALKER, LL.D., F.R.S., L. & E., &c., was born at Falkirk, N.B., in the year 1781. His education commenced at the school of that place, and was finished at the University of Glasgow. He had talent and was industrious; so that his studies were completed with distinction in a comparatively short time; and in the year 1800, when he was nineteen years of age, he was articled to his uncle, Mr. Ralph Walker, at that time an Engineer in considerable practice in London. Under him he was employed at the East and the West India Docks, and became conversant with the best class of constructions, eventually succeeding his uncle in the greater portion of his works.

Mr. Walker was intrusted, in 1803, with the formation of the Commercial Road, an important work, which was excellently carried out, and where he eventually tried the system of providing stone tramways for facilitating the traction of the heavy loads passing along that important route, from the docks to the metropolis.

He was appointed Engineer to the Commercial Docks in 1806, and the extensions and improvements effected up to the time of his death were designed by, and executed under, the superintendence of Mr. Walker and his partner, Mr. Burges.

At the decease of Mr. Telford, in 1834, many of his important works fell into the hands of Mr. Walker, and he was at that period, and for many years after, constantly consulted by almost all the branches of the Government, and by many public boards and corporations; especially that of the City of London, for which latter body he made numerous Reports upon the City sewers, and the navigation of the River Thames, projecting the plan of embankment, now known as 'Walker's lines;' upon which the present constructions are in a great degree based. He also had under his charge the bridges at Blackfriars and Westminster, executing extensive works for their maintenance, until their demolition was decided upon.

Any attempt to mention all the works upon which Mr. Walker had been engaged at some period of his long professional career, would involve the enumeration of nearly all the principal undertakings of the kingdom; but among them must be mentioned the construction of Vauxhall Bridge over the Thames, and of the Victoria Bridge over the Clyde, at Glasgow; the improvements of the River Clyde, which, from the death of Mr. Telford up to a recent date, were under his direction; the great repairs of the Caledonian and Crinan Canals; the Coffer Dam and River Wall of the New Houses of Parliament; the extensive works of the Birmingham Canal, including the Tame Valley Canal, the Betley Canal, and the Netherton Tunnel; the extensions of the Bute Docks at Cardiff; the Pier and Harbour of Granton; the improvements of the Harbour of Belfast, and the Harbour Works at Dover; the designs and execution of the Harbours of Refuge at Alderney, St. Catherine's, Jersey, Dover, and Harwich, on the former of which he was penning a Report in his own hand on the day before his decease; the Tyne Piers; the completion of Plymouth Breakwater, and the foundation for the Fort about to be constructed there for the War Department. But, perhaps, the most lasting monuments of his skill may be found in the various Lighthouse Works of the Corporation of the Trinity House. As a difficult and successful engineering work, the Bishop Rock Lighthouse, off the Scilly Islands, may be placed in the foremost rank with those of Smeaton, at the Edystone; of the elder Stevenson, at Bell Rock; and of that built on the Skerryvore, by Alan Stevenson, his son.

For many years the extensive drainage operations in the Fens, particularly in the Middle Level, occupied his attention; and the great cut, nearly 30 miles in length, by which, with its numerous branches, upwards of ninety thousand acres of valuable land are rendered susceptible of cultivation, is a work deserving the attention not only of the Engineer, but of the landowners in similar districts.

At an early period in the history of railways, Mr. Walker was appointed, in conjunction with the late Mr. Rastrick, to report on the system of traction to be employed on the Liverpool and Manchester Railway. Their recommendation was that a continuation of locomotive with stationary power should be used; but their Report was replied to so effectively by Robert Stephenson and Joseph Locke, that the celebrated Rainhill trials were instituted, and the locomotive system was fully established.

Mr. Walker never entered largely into railway engineering, preferring the other branches of the profession; but he did construct the Leeds and Selby, and the Hull and Selby Railways, both now forming valuable portions of the North Eastern system of lines.

The printed Reports proceeding from Mr. Walker's pen are very numerous, and they are valuable as giving the history of many important works. He was a strict disciplinarian, was very regular in his business habits, and indefatigable in his attention to the works under his charge. He was fortunate in attracting to him a number of men who have since risen to eminence in the profession; and he was very ably seconded by his partner, Mr. Burges, and subsequently by the late Mr. James Cooper.

Mr. Walker was connected with many of the principal scientific bodies of the kingdom. He was a fellow of the Royal Societies of London and of Edinburgh, LL.D. of Glasgow University, (an honour conferred only upon distinguished students of that body), a member of the Senate of the University of London, and an honorary member of several foreign societies.

He joined the Institution of Civil Engineers, as a Member, in the year 1823, was elected a Member of the Council and Vice-President in 1826, succeeding the first President, Mr. Telford, in 1834, and occupying the chair for nearly eleven years, during which time, by his attention to the interests of the Society, he contributed largely towards placing it in its present position. In the year 1845 it was considered desirable to introduce certain modifications in the constitution of the Society, one of the chief points being the limitation of the period of holding the post of President, in order to afford opportunity for the leading members of the profession to attain consecutively that honourable position. This and other proposals necessitated the revision of the Code of Bye-laws of the Institution, and, after several special meetings, the proposed modifications were carried, and Mr. Walker resigned the Presidential Chair, in which he was succeeded by Sir John Rennie, who occupied it for three years. Subsequent to that period no President has held the position longer than for two consecutive sessions.

Under the presidency of Mr. Walker the Institution made important strides; the number of the Members increased; the Society was enabled to remove to the present premises at No. 25, Great George Street, Westminster; the Annual Conversazioni were instituted, setting an example to all the other Socities of the metropolis; and the special feature of the Institution—the free expression of opinion, at the discussions upon the Papers—was largely encouraged. Mr. Walker had a peculiar talent for guiding the Meetings, and for eliciting the information possessed by the Members and the Visitors; and he was solicitous to have invitations issued to all those who were capable of contributing to the interest of the discussions, which he generally summed up very cleverly. His extensive acquaintance among scientific men and noblemen who felt an interest in the progress of Engineering science enabled him to induce many distinguished visitors to attend the Meetings, and, in some instances, to join the Society.

During the period of his filling the Presidential Chair, he liberally assisted the then comparatively young Society, as by his great wealth he could afford to do. The necessary alterations, however, in the constitution of the Society not meeting his views, he ceased to feel as great an interest as formerly; still, in his capacity of a Past-President, he was a not unfrequent attendant at the Meetings.

In spite of somewhat declining health, Mr. Walker continued to exercise his profession up to the period of his decease, and to the very last he retained his vigorous and shrewd intellect. He was eminently a man of business, and he had, at least, as much skill "in the engineering of men as of matter."

It has been correctly stated, that "his works were remarkable for their solidity and permanency, and not less for their utility, as having a material share in aiding the commercial progress of this country in the present century, during sixty years of which he had been in the active exercise of his noble profession."

He died on the 8th of October, 1862, and was interred, by his own desire, in his family vault, at St. John's episcopal burial-ground, at Edinburgh.

MR. WILLIAM WEALLENS was the descendant of a German family, who emigrated many years ago and settled in the North of England, in connection with some proposed steel works. Subsequently his immediate parents devoted themselves to agricultural pursuits, and his father, John Weallens, held a farm, called the East Houses, at North Dissington. His mother was the daughter of the Rev. John Furness, of Ponteland, where William Weallens was born, on the 8th of March, 1823. He received his education under Dr. Cowan, of the Grange, Bishopwearmouth, and having exhibited a talent for mechanical pursuits, he was apprenticed to Messrs. Robert Stephenson and Co., on the 3rd of September, 1838, and became the pupil of his stepfather, who took much pains with his professional education. His mother, who was early left a widow, with two sons and a daughter, married Mr. Hutchinson, who subsequently, as a reward for his faithful and efficient services, was admitted to a partnership in the celebrated firm of Messrs. Robert Stephenson and Co., of whose works he was the acting manager.

On the decease of Mr. Hutchinson, in 1853, the direction of the mechanical department of the works was intrusted to Mr. Weallens, and eventually, in January 1855, he was presented with a partnership in the firm, to whose concerns he devoted himself for some years with great energy. He was a very good mechanic, had clear judgment, and was fertile in resources. His temper was peculiarly amiable, and he endeared himself to the workmen and those with whom he came in contact by the gentleness of his disposition. These qualities were especially appreciated by the late Mr. Robert Stephenson, with whom he was a great favourite, and they were also recognized by his fellow-townsmen, who elected him a member of the Town Council. He took an active part in the Volunteer movement, commanded a company composed of men belonging to the works, and his example contributed essentially to the present state of efficiency of the corps. He joined the Institution of Civil Engineers, as a Member, in the year 1857, and was a Member of the Council of the Institution of Mechanical Engineers, of Birmingham.

His decease occurred almost suddenly, and in an unexpected manner. It had been the custom for him to make an annual visit to the Continent, generally with his friend Mr. Charles Manby. When the usual period for the journey approached, although they had both been somewhat indisposed, they did not see any reason for postponing their departure, but they travelled more leisurely than usual as far as Turin, where Mr. Weallens' state caused his companion so much uneasiness that he called in medical advice; but he was assured that the journey further south could be undertaken with safety, and probably even with benefit to the invalid. On arriving at Genoa, on consulting a physician of eminence, it was, however, thought desirable to return home, and Mr. Weallens was taken to Marseilles by sea, and thence, in a bed-carriage on the railway, to Paris, which was reached with comparatively little fatigue at seven o'clock on the evening of Saturday, the 1st of November, 1862. The best medical advice was immediately sought, but a sudden change occurred, and in spite of the most skilful treatment, the patient sunk rapidly, and expired at two o'clock on the morning of Sunday the 2nd of November, 1862. So tranquil was his end that the actual moment of his decease was only perceived from the inability to swallow the liquid which was administered to him in spoonsful at very short intervals, by Mr. Manby, who from the commencement of the serious attack had not left him, day or night.

His remains were brought to England, and were interred in the family vault at Ponteland, near Newcastle-on-Tyne, on Saturday, the 8th of November, 1862, when a well-deserved tribute of respect was paid to his memory by the attendance of his partners, a large number of his fellow-townsmen, the workmen from the factory, and a large body of Volunteers under arms, all anxious to pay the last tribute of respect to the memory of a man who had been so deservedly beloved and esteemed, and who, at the early age of 40 years, had been removed so suddenly from amidst a large circle of friends. A mural tablet was subsequently erected to his memory in the church at Ponteland, by a few of his attached friends.

LIEUTENANT-COLONEL JOHN FRASER LODDINGTON BADDELEY, Royal Artillery, Chevalier of the Legion of Honour, and of the Order of Medjidie, &c., was the sixth child of the late Major John Baddeley, Superintendent-General of the Barracks in Ireland, formerly of the 7th Hussars and 22nd Light Dragoons. At fifteen years of age young Baddeley joined the Military Academy, Woolwich, and at seventeen he obtained his commission in the Royal Artillery. His earliest services were in Ireland and in the West Indies, and on his return he was appointed to the Horse Artillery. On his promotion he was made Adjutant to the Tenth Battalion, but this appointment he resigned, and volunteered for the Crimea, where he was appointed Acting-Adjutant to Colonel Lake, R.A., and was attached to the Light Division under Sir George Brown. He was present at the actions at Boulganak, the Alma, Balaclava, and Inkerman, where he was dangerously wounded. He received the Crimean Medal with four clasps, the Legion of Honour, the Order of the Medjidie, and the Turkish Medal, and was appointed shortly afterwards second officer of the Royal Powder Works, Waltham Abbey, where he remained five years. He was subsequently made Assistant-Superintendent at the Royal Small Arms Factory, Enfield Lock, where he died, after one week's illness, aged thirty-six, leaving a widow and six children to deplore his early and untimely death.

The service thus lost an excellent officer, and the department to which he was attached, a most able and valuable assistant. The great mechanical abilities and untiring devotion to his duties which he exhibited during the period of his service at the Royal Gunpowder Factory at Waltham Abbey, as well as at the Royal Small Arms Factory, justly entitle his loss to be regarded in the light of a public one. The funeral of this much-lamented officer took place at Enfield on the 1st of March, 1862, and was conducted with more than the usual military honours due to his rank, being attended by a considerable body of troops, both regulars and volunteers. A spontaneous and most gratifying exhibition of feeling was shown by the workmen of the factories at Enfield and Waltham Abbey, who in a body of upwards of twelve hundred men accompanied the remains of the deceased officer to their last resting-place. The universal feeling of regret at the loss they have sustained, as well as the deep estimation in which he was held, have been shown by the publication of most creditable compositions in verse by workmen of the factory, and also by a subscription raised amongst themselves for the purpose of erecting a marble tablet in the church of the factory to the memory of their departed and acknowledged friend.

Lieutenant-Colonel Baddeley possessed all the qualifications for eventually attaining a very distinguished position. He had clear intuitive perception, good judgment, indefatigable industry, and had studied hard to extend his scientific and mechanical knowledge. To him may be ascribed the merit of the introduction to the service of the foreign mode of purifying saltpetre; and he published a tract, "On the Manufacture of Gunpowder, as carried on at the Government Factory, Waltham Abbey (1857.)"[1]

On becoming attached to the Royal Small Arms Factory, at Enfield, he immediately took a marked position; and if his life had been spared, he would have taken a very active and useful part in the War Office Manufacturing Department.

He was a general favourite in the branch of the service to which he belonged, and his decease was deeply and deservedly regretted by a large circle of friends.

Captain CARLTON THOMAS COLLINGWOOD joined the Institution of Civil Engineers as an Associate, in the year 1857; and died in India on the 7th of March, 1860.

It is regretted that repeated applications have failed to obtain any materials for a memoir.

Colonel SAMUEL COLT was born on the 19th of July, 1814, at Hartford, Connecticut, U.S., America. He was of Scotch descent, his father, Christian Colt, being the son of an early settler in Connecticut.

Sam Colt had not the advantage of careful education, and at a very early age he ran away to sea, and made several voyages to India. He had latent mechanical talent and great energy, and it is stated that he was constantly devising some supposed improvements in the tackle, &c., on board, for which the commander did not award him the credit which he imagined was his due; and he turned his attention to a repeating fire-arm which should be also a breech-loader, and thus afford to the solitary pioneers of the Western States the immunity from danger which only could be obtained by rapid firing, in case of attack by the Indians. Whilst at sea he is supposed to have produced the first wooden model of the revolver pistol which bears his name; and it has been asserted that, on his return to America, he fell in with another untaught inventor, like himself, whose attention had also been directed to the same subject, and that he received from this accidental acquaintance the first notions of the necessity of adopting mechanical and automatic machinery for the production of these weapons. For some years he had to struggle with great difficulties, and during that period he turned his attention to other subjects; but always keeping in view the production by machinery of the several parts of the repeating fire-arm, and for this he invented and adapted various machines. He received his first patent in 1835, and established a factory in Paterson, New Jersey, but met with indifferent success. He subsequently disposed of his right to manufacture revolving fire-arms, and, as it was generally understood at the time, expended the proceeds in a vain attempt to clear his brother, John C. Colt, of a charge of homicide. Sam Colt afterwards invented a submarine torpedo, which was intended for the destruction of vessels. He gave two exhibitions of the power of his new invention in the bay off Castle Garden, by blowing up first a schooner, and afterwards a large brig. He then established a line of telegraph between New York and Sandy Hook and Montauk, which was intended to announce the arrival of vessels, and to facilitate the despatch of important foreign news; but this enterprise failed, and he became very much reduced in circumstances. Colonel Colt is also reputed to have been the inventor of the first submarine telegraph cable, as shown and tested from Fire Island to New York, and from the Merchant's Exchange to the mouth of the harbour, in 1843. A few years later he again obtained possession of his patent for the revolving pistol, and with the assistance of a few capitalists who joined him, a company was formed and a manufactory was established at Hartford, which has proved very successful, not only in the making of pistols, but in the manufacture of a revolving rifle, which was also the invention of Sam Colt. The factory was supposed, before the war, to be worth nearly $5,000,000, and since then has, most probably, considerably augmented in value. The proceeds have been so great, that Colonel Colt realised a large landed estate, and he was no doubt one of the wealthiest men in New England.

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[1] Library Inst. C.E. Tract 8vo. vol. cxx.

At the period of the International Exhibition in 1851, Colonel Colt first visited London, but so little was generally known of the use of repeating fire-arms, that "Colt's Revolvers" scarcely attracted any attention, and it was only towards the time of the closing of the Exhibition that General Gibbs MacNeill (U.S. army), who had experience of the value of these arms in the Texan and other expeditions, directed to them the attention of some Members of the Institution of Civil Engineers, by one of whom a Paper was written, from the information given by Colonel Colt, describing the automatic machinery used in the production of these weapons. The Paper[1] was read, and the subject was discussed at two meetings of the Institution in the month of November 1851. This induced the attention of the Government to the mode of manufacture, and Colonel Colt was permitted to establish a small-arms factory in a building belonging to the Government at Thames Bank, Pimlico. This was not successful as a commercial speculation, but it had the result of inducing the attention of the intelligent gunmakers of the metropolis and the provinces to the subject, and eventually at the Government Small Arms Factory at Enfield, the same kind of automatic machinery was adopted, with the present evident beneficial result for Her Majesty's service. This is another instance, among many, of the too general neglect of useful inventions from abroad, and their eventual forced introduction. In this case Colonel Colt lost a large sum of money, and the Engineer who introduced him and the repeating arm to the Institution, the Government, and the public, and wrote the article in question, is not publicly known in connection with the subject. After the closing of the manufacture at Thames Bank, Colonel Colt returned to America, and on the breaking out of the war, he used great exertions to extend the production of arms, supplying also considerable funds for raising a corps of men for the service of the Northern army. He is stated to have greatly extended the Hartford works, and to have realized a very large fortune.

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[1] *Vide* Minutes of Proceedings, Inst. C.E. vol. xi. p. 30.

His decease occurred, from disease of the brain, on the 9th of January, 1862, in the forty-eighth year of his age. He was a man of determined will, of great natural powers, and only lacked the advantages of early education and training to have become a man of mark in his generation.

He joined the Institution as an Associate in the year 1852, and received a Telford Medal for the Paper already referred to.

Mr. ROBERT COWEN was born at Biglands, near Wigton, Cumberland, in 1787. He received the rudiments of his education at the village school, and from youth onwards he was a diligent self-instructor. At the early age of fifteen he was associated with his father in the management of the cotton-mill carried on in Carlisle by the firm of Cowen, Heysham, and Co. In a short time he was found capable of taking upon himself the entire direction of the machinery department, and few young men, at their entrance into life, ever more closely attended to the duties of their allotted position than Mr. Cowen did. Although the long hours and rigid rules of a cotton-spinning establishment leave the persons engaged in it but little leisure, Mr. Cowen contrived, by systematic application, to extend his knowledge of scientific subjects. Mechanics were especially his delight, and his proficiency was shown by improvements in the spinning and carding machinery, which essentially contributed to the success which attended the house. In process of time the style of the firm was altered to Jacob Cowen and Sons, and Mr. Robert Cowen became a partner in the concern with which he continued to be connected for so many years. Without neglecting the business, he found time for pursuing his studies, and there were few men who better understood the principles and practice of mechanics. His knowledge, in fact, extended to most of the sciences and the useful arts: and, amidst his active engagements, he was still able to cultivate the arts of drawing, painting, sculpture, and engraving: but this stringent taxing of the mental powers produced their natural effects upon the body, and up to his fortieth year Mr. Cowen was an ailing man, and very reluctantly mixed with society.

He was, however, hospitable in an eminent degree, but he was not a demonstrative man, and he was never heard to boast of what he had done or intended to do. He shrank from display, save in the matter of the fine arts, and his love for and patronage of them was demonstrated by the possession of an unusually large collection of paintings and sculpture, a well-selected library of sterling books, and a great number of valuable engravings and drawings. Few private residences contained more or better selected attractions.

At a somewhat early period of his career, in 1824, Mr. Cowen had conferred on him by the Society of Arts the Gold Vulcan Medal[1] "for his improved method of carrying off the Dust produced in grinding Cotton Cards," which, up to that date, the workmen of Sheffield and elsewhere were compelled to inhale at the terrible cost of lung-disease and premature death. In 1827, he received a second gold medal from the same Society[2] for his Draining Syphon; a practical and useful invention for the extraction of liquids from large vessels, and water from pools, lakes, &c., below the ordinary level, or for raising water from lower to higher levels.

In due time Mr. Cowen, having to some extent retired from the active management of the mills, determined to gratify the natural bent of his inclinations, and to adopt the profession of a Civil Engineer, for which he was technically qualified by his mechanical knowledge and practice, and theoretically by his intimate acquaintance with the applied sciences. He took a very active and useful part in the improvement of the City of Carlisle, promoted the establishment of water and gas works, of which latter he became the Chairman, and by his influence enabled the Company to avoid expensive litigation. He held the office of Government Inspector of Steam Boat Machinery for a part of the Solway. He was in the Commission of the Peace for the County of Northumberland and the City of Carlisle, of which also he, for some time, was an alderman and town-councillor; and there was scarcely a charitable institution in the town that had not the benefit of his pecuniary support.

To several young men who have since risen to honourable positions he afforded timely and effectual aid, and among them must be especially mentioned the late Mr. Joseph Miller, F.R.S., M. Inst.

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[1] *Vide* "Transactions of the Society of Arts," vol. xliv. p. 132.
[2] *Ibid.*, vol. xlv. p. 113.

C.E., &c., to whom the advice and assistance he rendered in early life was most valuable, and it was always gratefully acknowledged. In later years, when Mr. Miller had attained his deservedly high reputation as an Engineer, he delighted to recall the advantages he received from the precepts and example of Mr. Cowen, and they remained fast friends through life.

Mr. Cowen joined the Institution of Civil Engineers as an Associate in the year 1841, and always took much interest in its welfare.

"He died on Sunday afternoon, 27th April, 1862, at his house in Devonshire Street, Carlisle, in the 75th year of his age, after a long course of sickness and suffering; but, in the closing stages of his decline, although his bodily strength failed, and his form became greatly attenuated, his mental powers and memory were mercifully preserved to him in perfection, and enabled him to direct all that a man must wish to have done who is conscious that he is on the point of yielding up his breath to Him who gave it. His complaint was hereditary gout of great severity, involving a complication of ills and acute pains. He, however, bore his affliction with fortitude and resignation. He had no desire to live; he looked beyond this world. He said, in reply to the inquiries of a friend, that 'he had made his peace.' The troubles and cares of life at an end, he sleeps soundly. Those who well knew him and appreciated his worth will never cease to cherish and honour his memory."

MR. JOHN WITHERS, of Whalley Abbey, joined the Institution of Civil Engineers as an Associate in the year 1857. He died on the 25th October, 1862, at the age of 43 years.

All attempts to obtain materials for a Memoir have been unsuccessful.

MR. JOHN BRANNIS BIRCH, F.G.S., was born in London in the year 1813. He studied architecture and surveying under his father, and subsequently embraced the profession of a Civil Engineer. At an early period of his career he entered into partnership with his brother, Eugenius Birch (M. Inst. C.E.), a connection which continued up to the period of the death of J. B. Birch. He was actively engaged in works of varied character up to 1845, when he took a prominent part, as Engineer, in the parliamentary survey and sections of several important lines of railway. He was then engaged in laying out the section of the East Indian Railway from Calcutta to Delhi, and with his brother designed the whole of the bridges and viaducts, and upon the material thus furnished the guarantee of the line was obtained. He was subsequently employed in the construction of several works of interest and public utility, among which may be mentioned the Margate Pier, which was erected in 1853 from the designs and under the supervision of his brother and himself. It is remarkable as being a very early example of the complete adaptation of iron as the material in the formation of sea structures of that kind.

He was elected a Graduate of the Institution of Civil Engineers in 1842, and in that capacity he remained to the time of his death. He became a Fellow of the Geological Society in 1847, and a considerable portion of his leisure time was devoted to geological researches, in which he took an interest second only to that with which he regarded the works of the profession he had so happily chosen for himself, and which he for so many years earnestly and zealously pursued.

He died in London on the 17th of June, 1862, deeply regretted by all his connections and friends.

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LONDON:
PRINTED BY WILLIAM CLOWES AND SONS, STAMFORD STREET
AND CHARING CROSS.

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